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NC 7th Grade Genetics

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Chapter 1

MS Studying the Life Sciences

How many questions can you ask about the sun? Why does the sun shine? How does it move across the sky? How does it help plants grow? What would happen to life on Earth if the sun failed to rise tomorrow? You could ask all of these questions, and probably many more. When scientists observe the physical world, they ask questions like these and then try to answer them.

Before science, these types of questions were answered by beliefs and myths. For example, ancient Aztec societies believed the sun would not rise unless they performed human sacrifices. Science teaches us that we need evidence that can explain our observations. In this chapter, we will explore how science can help us ask and answer the questions we have about our physical world.

1.1 Scientific Ways of Thinking

Lesson Objectives

- Describe the role of a scientist.
- Understand that science is a system based on evidence, testing, and reasoning.

Vocabulary

- evidence
- experiment

Modern Science

Modern science is:

1. A way of understanding the physical world, based on observable evidence, reasoning, and repeated testing.
2. A body of knowledge that is based on observable evidence, experimentation, reasoning, and repeated testing.

Thinking Like a Scientist

How can you think like a scientist?

- **Scientists ask questions:** The key to being a great scientist is to ask questions. Imagine you are a scientist in the African Congo. While in the field, you observe one group of healthy chimpanzees on the North side of the jungle. On the other side of the jungle, you find a group of chimpanzees that are mysteriously dying. What questions might you ask? A good scientist will ask, "What differs between the two environments where the chimpanzees live?" and "Are there differences in behavior between the two chimps that allow one group to survive over another?"
- **Scientists make detailed observations:** A person untrained in the sciences may observe, "The chimps on one side of the jungle are dying, while chimps on the other side of the jungle are healthy." Can you think of ways to make this observation more detailed? What about the number of chimps? Are they male of female? Young or old? A good scientist may observe, "While all seven females and three males on the North side of the jungle are healthy and show normal behavior, four female and five male chimps under the age of five have died." Detailed observations can ultimately help scientists to design their experiments and answer their questions. See a photo of chimpanzees in **Figure** 1.1.

- **Scientists find answers using tests:** When scientists want to answer a question, they search for evidence using experiments. An **experiment** is a test to see if a hypothesis is right or wrong. **Evidence** is made up of the observations a scientist makes during an experiment. To study the cause of death in the chimpanzees, scientists may give the chimps nutrients in the form of nuts, berries, and vitamins to see if they are dying from a lack of food. This test is the experiment. If fewer chimps die, then the experiment shows that the chimps may have died from not having enough food. This is the evidence.

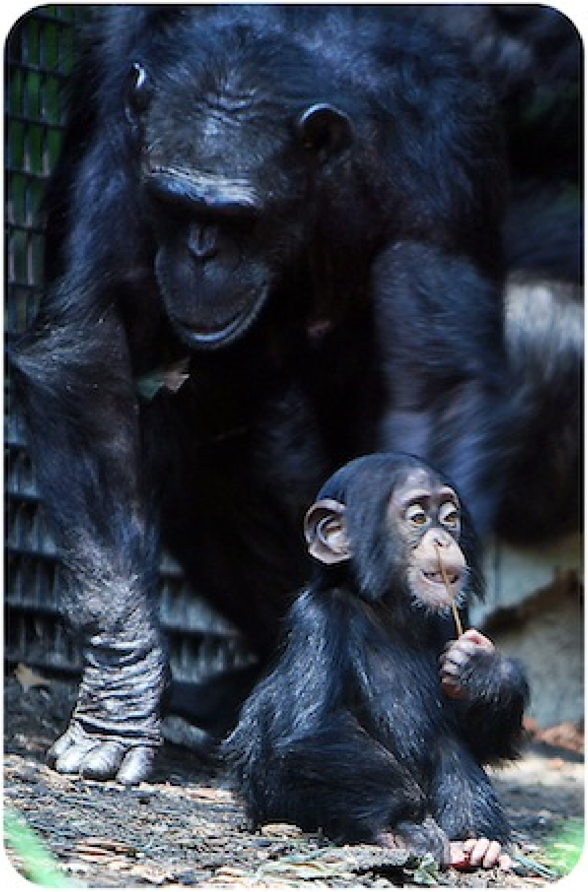

Figure 1.1: An adult and child chimpanzee.

- **Scientists question the answers:** Good scientists are skeptical. Scientists never use only one piece of evidence to form a conclusion. For example, the chimpanzees in the experiment may have died from a lack of food, but can you think of another explanation for their death? They may have died from a virus, or from another less obvious cause. More experiments need to be completed before scientists can be sure. Good scientists constantly question their own conclusions. They also find other scientists to confirm or disagree with their evidence.

1.2 What Are the Life Sciences?

Lesson Objectives

- Define Life Science.
- Describe how evidence is used to create and support scientific theories.

Vocabulary

- cell theory
- life science
- scientific theory
- theory of evolution

Fields in the Life Sciences

The **life sciences** are the study of living organisms, and how they interact with each other and their environment. Life sciences deal with every aspect of living organisms.

The life sciences are so complex that most scientists focus on just one or two subspecialties. If you want to study insects, what would you be called? An entomologist. If you want to study the tiny things that give us the flu, then you need to enter the field of virology. Look at **Table** 1.1, **Table** 1.2, and **Table** 1.3. If you want to study the nervous system, what life sciences field is right for you?

Table 1.1: **Subspecialties that focus on one type of organism**

Subspecialty	Studies	Subspecialty	Studies
Botany	plants	**Zoology**	animals
Marine biology	organisms living in and around oceans, and seas	**Fresh water biology**	organisms living in and around freshwater lakes, streams, rivers, ponds, etc.
Microbiology	microorganisms	**Bacteriology**	bacteria
Virology	viruses (see **Figure** 1.2)	**Entomology**	insects
Taxonomy	the classification of organisms		

Table 1.2: **Fields of life sciences that examine the structure, function, growth, development and/or evolution of living things**

Life Science	What it Examines	Life Science	What it Examines
Cell biology	cells and their structures (see **Figure** 1.2)	**Anatomy**	the structures of animals
Morphology	the form and structure of living organisms	**Physiology**	the physical and chemical functions of tissues and organs

Table 1.2: (continued)

Life Science	What it Examines	Life Science	What it Examines
Immunology	the mechanisms inside organisms that protect them from disease and infection	**Neuroscience**	the nervous system
Developmental biology and embryology	the growth and development of plants and animals	**Genetics**	the genetic make up of all living organisms (heredity)
Biochemistry	the chemistry of living organisms	**Molecular biology**	biology at the molecular level
Epidemiology	how diseases arise and spread		

Table 1.3: **Fields of biology that examine the distribution and interactions between organisms and their environments**

Life Science	What it Examines	Life Science	What it Examines
Ecology	how various organisms interact with their environments	**Biogeography**	the distribution of living organisms (see **Figure** 1.3)
Population biology	the biodiversity, evolution, and environmental biology of populations of organisms		

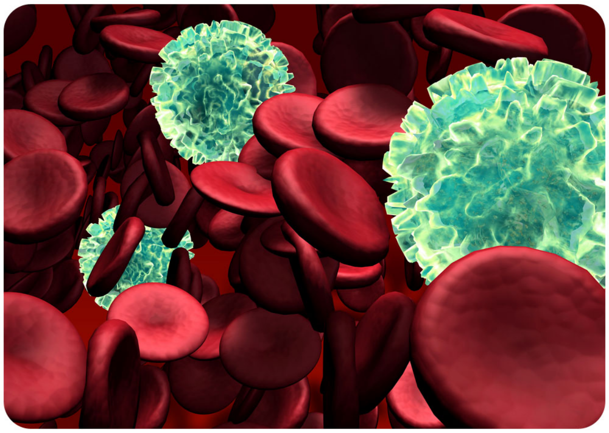

Figure 1.2: This drawing shows red blood cells and viruses. Virology is the study of viruses. Cell biology is the study of cells.

Scientific Evidence and Theories in the Life Sciences

Scientists perform experiments and collect evidence. Evidence is:

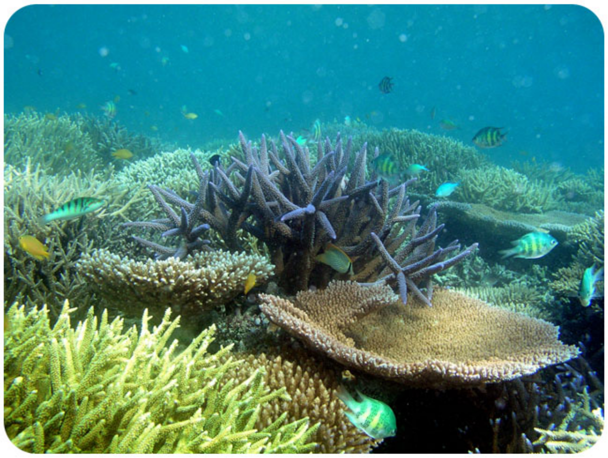

Figure 1.3: Biogeography looks at the variation of life forms within a given ecosystem, biome, or for the entire Earth. In other words, it tries to explain where organisms live and at what abundance.

1. A direct, physical observation of a thing, a group of things, or a process over time.
2. Usually something measurable or "quantifiable."
3. The data resulting from an experiment.

For example, an apple falling to the ground is evidence in support of the theory of gravity (**Figure** 1.4). A bear skeleton in the woods would be evidence of the presence of bears.

Scientific theories are well established and tested explanations of observations or evidence. Scientific theories are produced through repeated experiments. Theories are usually tested and confirmed by many different people.

Scientific theories produce information that helps us understand our world. For example, the idea that matter is made up of atoms is a scientific theory. Scientists accept this theory as a fundamental principle of basic science. However, when scientists find new evidence, they can change their theories.

The following are links to information about the nature of science:

- `http://www.project2061.org/publications/bsl/online/index.php?chapter=1`
- `http://evolution.berkeley.edu/evosite/nature/index.shtml`

Two Important Life Science Theories

In the many life sciences, there are possibly hundreds or thousands of theories. The field of modern biology, however, really depends on two especially significant theories. They are:

1. **The Cell Theory**
2. **The Theory of Evolution.**

The Cell Theory

The Cell Theory states that:

1. All organisms are composed of cells (**Figure** 1.5).
2. Cells are the basic units of structure and function in an organism.

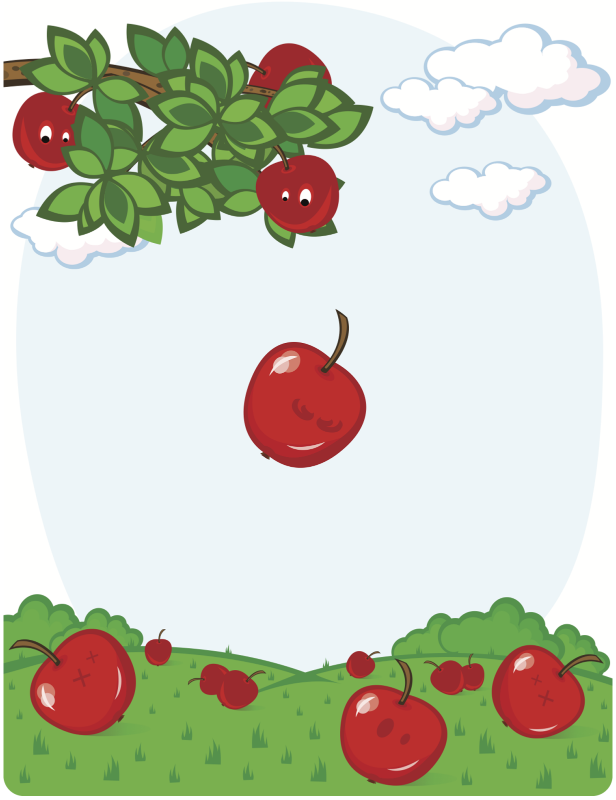

Figure 1.4: An apple falls from a tree to the ground, instead of floating in space. This is evidence for the theory of gravity.

3. Cells only come from preexisting cells; life comes from life.

The development of the microscope in the mid 1600s made it possible for scientists to develop this theory (**Figure** 1.6).

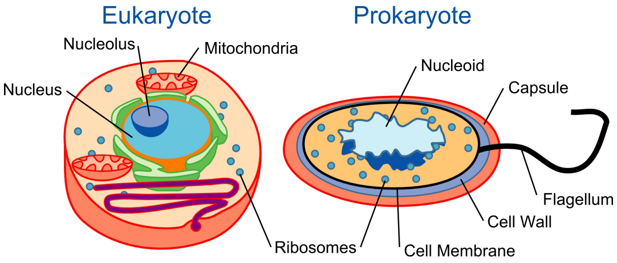

Figure 1.5: The two types of cells, eukaryotic (left) and prokaryotic (right).

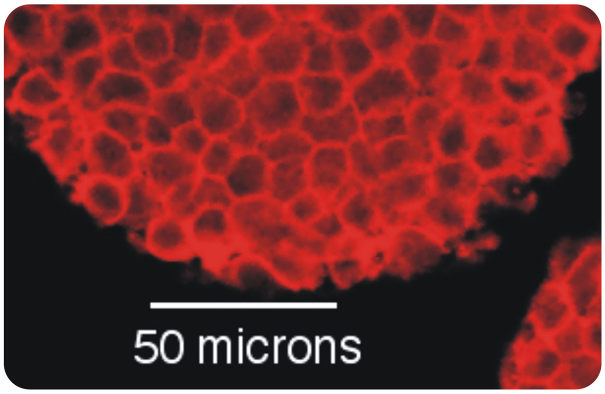

Figure 1.6: A mouse cell viewed through a microscope.

The Theory of Evolution

The Theory of Evolution explains how populations of organisms can change over time. It also explains why there are many different types of organisms on Earth. This theory is often called the "great unifier" of biology, because it applies to every field of biology. It also explains how all living organisms on Earth come from common ancestors (**Figure** 1.7). You will learn more about the details of the theory of evolution in later chapters.

An introduction to evolution and natural selection can be viewed at `http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/0/GcjgWov7mTM`.

Lesson Summary

- Science is a way of understanding about the physical world.
- Science is based on evidence, reasoning, and testing predictions.
- Information that has been thoroughly tested can still undergo further testing and revisions, as new evidence and questioning are raised.
- Science differs from other ways of knowing because it is entirely based on observable evidence.
- Scientific explanations are constantly questioned and tested.
- Science produces theories and general knowledge.

Figure 1.7: Evolution explains the millions of varieties of organisms on Earth.

Figure 1.8: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/98

- Science allows us to better understand the world.
- Science allows us to apply this knowledge to solve problems.

Review Questions

Recall

1. What do all fields of life science have in common?
2. What are the three characteristics of evidence?
3. What is the goal of science?

Apply Concepts

4. What would you study if you were a biogeographer?
5. Why do you think the development of microscopes led to the development of the Cell Theory?

Think Critically

6. What do you think the difference is between a theory and a set of observations?
7. If all cells come from pre-existing cells, where do you think the first cells came from?

Further Reading / Supplemental Links

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Points to Consider

Next we discuss the scientific method.

- How does thinking like a scientist allow us to answer questions about life?
- What is the difference between science completed in a laboratory and science completed outside?

1.3 The Scientific Method

Lesson Objectives

- Describe the scientific method as a process.
- Explain why the scientific method allows scientists and others to examine the physical world more objectively than other ways of knowing.
- Describe the steps involved in the scientific method.

Vocabulary

- applied science
- basic science
- hypothesis
- scientific method

The Scientific Method

The **scientific method** is a process used to investigate the unknown. This process uses evidence and testing. Scientists use the scientific method so they can find information. A common method allows all scientists to answer questions in a similar way. Scientists who use this method can reproduce another scientist's experiments. Why do you think it is important that scientists reproduce each other's experiments?

Almost all versions of the scientific method include the following steps, though not always in the same order:

1. Make observations
2. Identify a question you would like to answer based on the observation
3. Find out what is already known about your observation (research)
4. Form a hypothesis
5. Test the hypothesis
6. Analyze your results
7. Communicate your results

Making Observations

Imagine that you are scientist. While collecting water samples at a local pond, you notice a frog with five legs instead of four (**Figure** 1.9). As you start to look around, you discover that many of the frogs have extra limbs, extra eyes or no eyes. One frog even has limbs coming out of its mouth. These are your **observations**, or things you notice about an environment using your five senses.

Identify a Question Based on Your Observations

The next step is to ask a question about the frogs. You may ask, "Why are so many frogs are deformed?" Or, "Is there something in their environment causing these defects, like water pollution?"

Yet, you do not know if this large number of deformities is "normal" for frogs. What if many of the frogs found in ponds and lakes all over the world have similar deformities? Before you look for causes, you

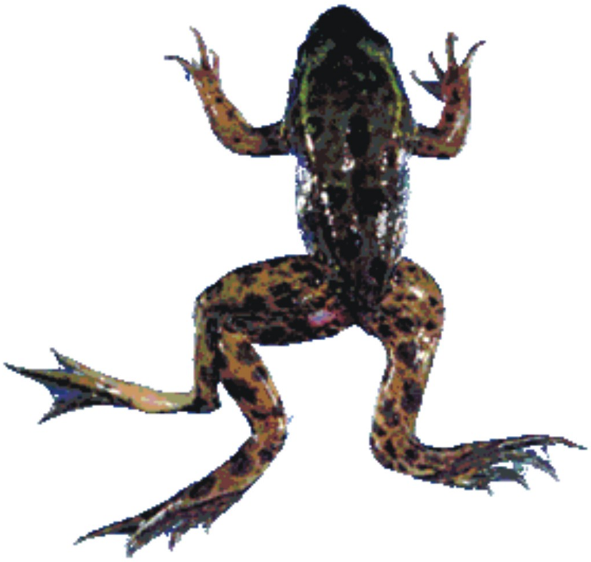


Figure 1.9: A frog with an extra leg.

need to find out if the number and kind of deformities is unusual. So besides finding out *why* the frogs are deformed, you should also ask: ”Is the percentage of deformed frogs in this pond greater than the percentage of deformed frogs in other places?” (**Figure** 1.10)

Figure 1.10: A pond with frogs.

Research Existing Knowledge About the Topic

No matter what you observe, you need to find out what is already known about your questions. For example, is anyone else doing research on deformed frogs? If yes, what did they find out? Do you think that you should repeat their research to see if it can be duplicated? During your research, you might learn something that convinces you to change or refine your question.

Construct a Hypothesis

A **hypothesis** is an educated guess that tries to explain an observation. A good hypothesis allows you to make more predictions. For example, you might hypothesize that a pesticide from a nearby farm is running into the pond and causing frogs to have extra legs. If that's true, then you can predict that the water in a pond of non-deformed frogs will have lower levels of that pesticide.

That's a prediction you can test by measuring pesticide levels in two sets of ponds, those with deformed frogs and those with nothing but healthy frogs. Every hypothesis needs to be written in a way that it can:

1. Be tested using evidence.
2. Be proven wrong.
3. Provide measurable results.
4. Provide yes or no answers.

For example, do you think the following hypothesis meets the four criteria above? Let's see. Hypothesis: "The number of deformed frogs in five ponds that are polluted with chemical X is higher than the number of deformed frogs in five ponds without chemical X."

Test Your Hypothesis

To test the hypothesis, you would count the healthy and deformed frogs and measure the amount of chemical X in all of the ponds. The hypothesis will be either true or false. Here is an example of a hypothesis that is not testable: "The frogs are deformed because someone cast a magic spell on them." You cannot test a magic hypothesis or measure any results of magic. Doing an experiment will test most hypotheses. The experiment may generate evidence in support of the hypothesis. The experiment may also generate evidence proving the hypothesis false.

Analyze Data and Draw a Conclusion

If a hypothesis and experiment are well-designed, the experiment will produce results that you can measure, collect, and analyze. The **analysis** should tell you if the hypothesis is true or false. See **Table** 1.4 for the experimental results.

Table 1.4:

Polluted Pond	**Number of Deformed Frogs**	**Non-polluted Pond**	**Number of Deformed Frogs**
1	20	1	23
2	23	2	25
3	25	3	30
4	26	4	16
5	21	5	20
Average:	23	Average:	22.8

Your results show that pesticide levels in the two sets of ponds are different, but the average number of deformed frogs is almost the same. Your results demonstrate that your hypothesis is false. The situation may be more complicated than you thought. This gives you new information that will help you decide what to do next. Even if the results supported your hypothesis, you would probably ask a new question to try to better understand what is happening to the frogs and why.

Drawing Conclusions and Communicating Results

If a hypothesis and experiment are well-designed, the results will tell whether your hypothesis is true or false. If a hypothesis is true, scientists will often continuing testing the hypothesis in new ways to learn more. If a hypothesis is false, the results may be used to come up with and test a new hypothesis.

Scientists communicate their results in a number of ways. For example, they may talk to small groups of scientists and give talks at large scientific meetings. They will write articles for scientific journals. Their findings may also be communicated to journalists.

If you conclude that frogs are deformed due to a pesticide not previously measured, you would publish an article and give talks about your research. Your conclusion could eventually help find solutions to this problem.

Basic and Applied Science

Science can be ”basic” or ”applied.” The goal of **basic science** is to understand how things work - whether it is a cell or a whole ecosystem. Basic science is the source of most scientific theories and new knowledge. For example, a scientist that tries to find the right drug to treat brain injuries is performing basic science.

Applied science is using scientific discoveries to solve practical problems. Applied science also creates new technologies. For example, medicine and all that is known about how to treat patients is applied science based on basic research (**Figure** 1.11). A doctor administering a drug or performing surgery on a patient is an example of applied science.

Figure 1.11: Surgeons operating on a person, an example of applied science.

Lesson Summary

- The scientific method is a process used to investigate questions.
- The scientific method uses observable evidence and testing.

- A hypothesis is a proposed explanation of an observation; it is used to test an idea.
- A hypothesis must be written in a way that can be tested, can be proved false, can be measured, and will help answer the original question.
- Basic research produces knowledge and theories.
- Applied research uses knowledge and theories from basic research to develop solutions to practical problems.

Review Questions

Recall

1. What does a hypothesis need to include?

2. What does ”falsifiable” mean?

3. List the steps of the Scientific Method.

Apply Concepts

4. How is a hypothesis different from a theory?

5. A doctor treats a patient with HIV with a new anti-viral drug. Is this an example of basic or applied science?

Think Critically

6. What does a scientist do if their research contradicts previous theories or popular knowledge?

7. A field scientist studies mice and observes that mice in the desert have fewer offspring (children) than mice in the forest. She hypothesizes that mice in the desert have access to less water and therefore have fewer offspring to conserve the much-needed resource. Is this a testable hypothesis? Why or why not?

Further Reading / Supplemental Links

- William Souder, A Plague of Frogs: The Horrifying True Story. Hyperion Press, 2000.

Points to Consider

- How do you think scientific “tools” can help scientists?
- What do you think is one of the more common tools of the life scientist?

1.4 Tools of Science

Lesson Objectives

- Describe the growing number of tools available to investigate different features of the physical world.
- Describe how microscopes have allowed humans to view increasingly small tissues and organisms that were never visible before.

Vocabulary

- electron microscope
- microscope
- microscopy
- optical (light) microscope
- scanning acoustic microscope
- scanning electron microscope (SEM)
- transmission electron microscope (TEM)

Using Microscopes

Microscopes, tools that you may get to use in your class, are some of the most important tools in biology (**Figure** 1.12). Look at your fingertips. Before microscopes were invented in 1595, the smallest things you could see on yourself were the tiny lines in your skin. But what else is hidden in your skin?

Over four hundred years ago, two Dutch spectacle makers, Zaccharias Janssen and his son Hans, were experimenting with several lenses in a tube. They discovered that nearby objects appeared greatly enlarged. That was the forerunner of the compound microscope and of the telescope. Later, the father of microscopy, Dutch scientist Antoine van Leeuwenhoek (**Figure** 1.13) taught himself to make one of the first microscopes (**Figure** 1.14). A **microscope** is a tool used to make things that are too small to be seen by the human eye look bigger. **Microscopy** is a technology for studying small objects using microscopes.

In 1665, Robert Hooke, an English natural scientist, used a microscope to zoom in on a piece of cork — the stuff that makes up the stoppers in wine bottles. Inside of cork, he discovered the smallest building blocks of life, or **cells** (**Figure** 1.15 and **Figure** 1.16). This finding eventually led to the development of the theory that *all living things are made up of cells.* Without microscopes, this theory would not have been developed.

In one of his early experiments, van Leeuwenhoek took a sample of scum from his own teeth and used his microscope to discover bacteria, one of the tiniest living organisms on the planet. Using microscopes, van Leeuwenhoek also discovered one-celled organisms (protists) and sperm.

Some modern microscopes use light, as Hooke's and van Leeuwenhoek's did, but others may use electron beams or sound waves.

Researchers now use these types of microscopes:

1. **Light microscopes** allow biologists to see small details of a specimen. Most of the microscopes used in schools and laboratories are light microscopes. Light microscopes use refractive lenses, typically made of glass or plastic, to focus light either into the eye, a camera, or some other light detector. The most powerful light microscopes can make images up to 2,000 times larger.
2. **Transmission electron microscopes (TEM)** focus a beam of electrons through an object and can make an image up to two million times bigger, with a very clear image (”high resolution”).

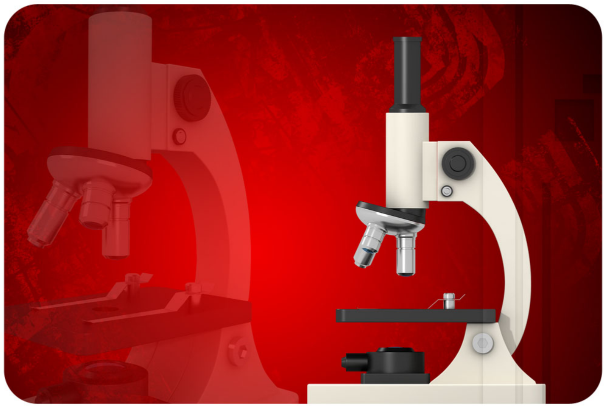


Figure 1.12: Basic light microscopes opened up a new world to curious people. See if you can identify the following parts of the microscope: 1, ocular lens or eyepiece; 2, objective turret; 3, objective lenses; 4, coarse adjustment knob; 5, fine adjustment knob; 6, object holder or stage; 7, mirror or light (illuminator); 8, diaphragm and condenser.

Figure 1.13: Antoine van Leeuwenhoek, a Dutch cloth merchant with a passion for microscopy.

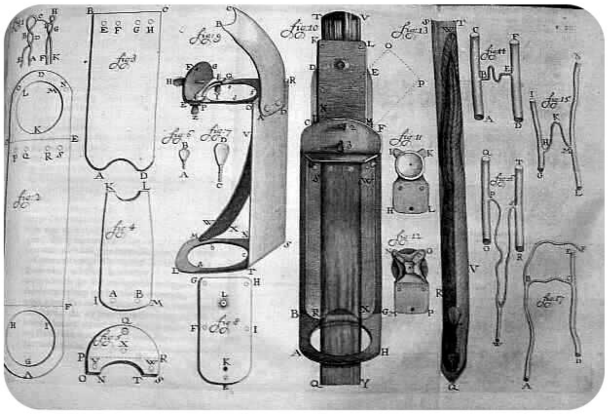


Figure 1.14: Drawing of microscopes owned by Antoine van Leeuwenhoek. Bacteria were discovered in 1683 when Antoine Van Leeuwenhoek used a microscope he built to look at the plaque on his own teeth.

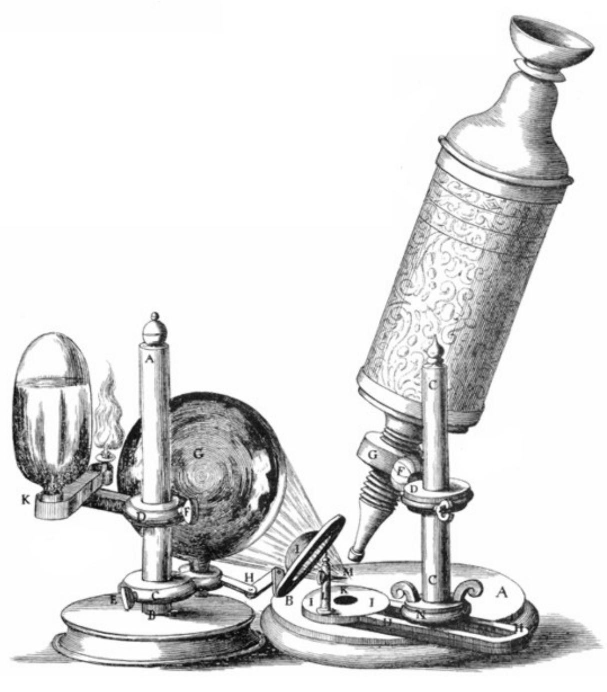


Figure 1.15: Robert Hooke's early microscope.

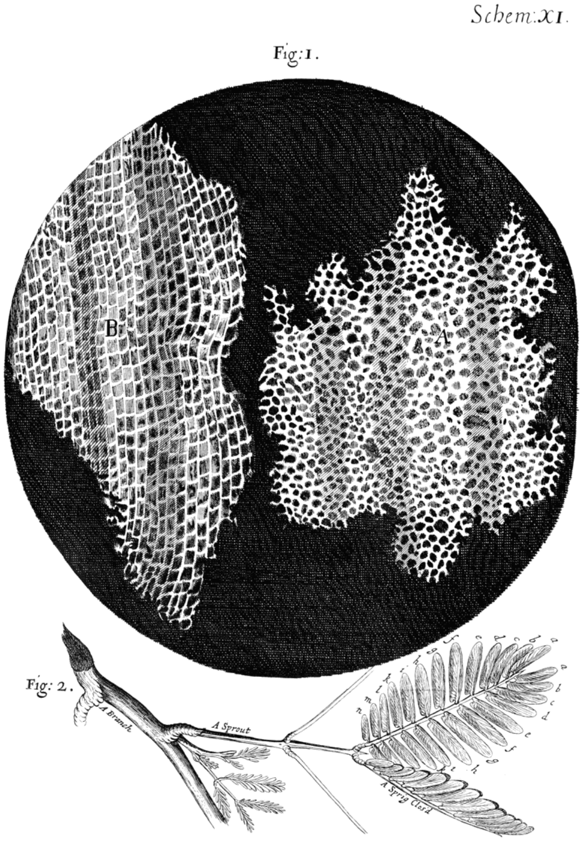


Figure 1.16: Cell structure of cork by Hooke.

3. **Scanning electron microscopes (SEM)** (**Figure** 1.17 and **Figure** 1.18) allow scientists to find the shape and surface texture of extremely small objects, including a paperclip, a bedbug, or even an atom. These microscopes slide a beam of electrons across the surface of a specimen, producing detailed maps of the shapes of objects. Visit the following site to see incredible images of tiny organisms and objects using an electron scanning microscope: `http://www.mos.org/sln/sem/sem.html`
4. **Scanning acoustic microscopes** use sound waves to scan a specimen. These microscopes are useful in biology and medical research.

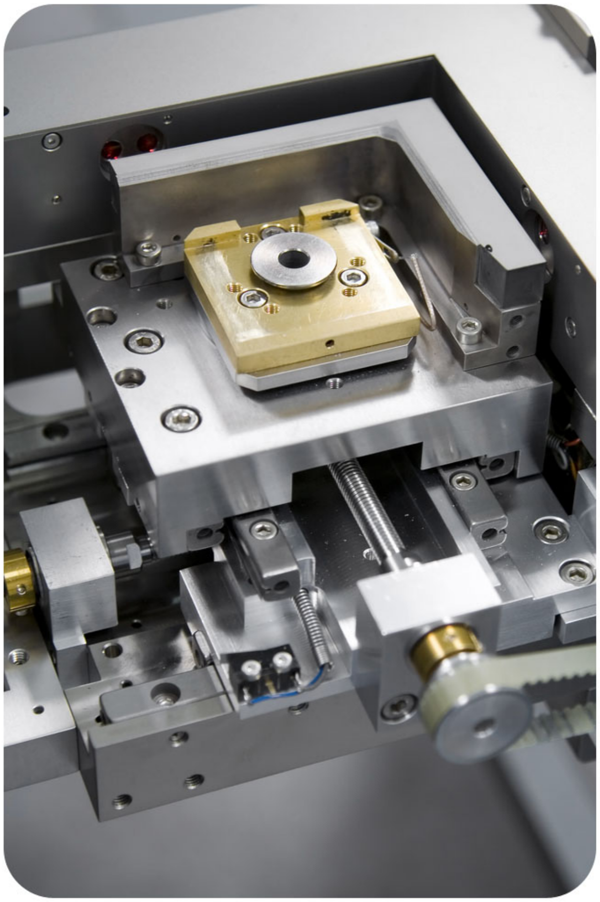


Figure 1.17: A scanning electron microscope.

Other Life Science Tools

What other kinds of tools and instruments would you expect to find in a biologist's laboratory or field station? Other than computers and lab notebooks, biologists use very different instruments and tools for the wide range of life science specialties. For example, a medical research laboratory and a marine biology field station might not use any of the same tools.

Tools such as a radiotelemetry device (**Figure** 1.19), a thermocycler (**Figure** 1.20) and inoculation (sterile) hoods (**Figure** 1.21) are all biological equipment.

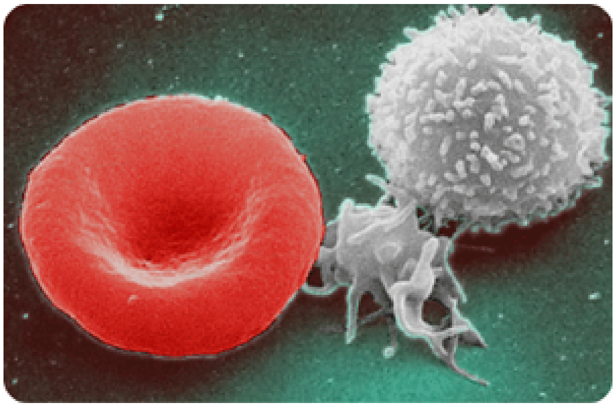


Figure 1.18: A scanning electron microscope image of blood cells.

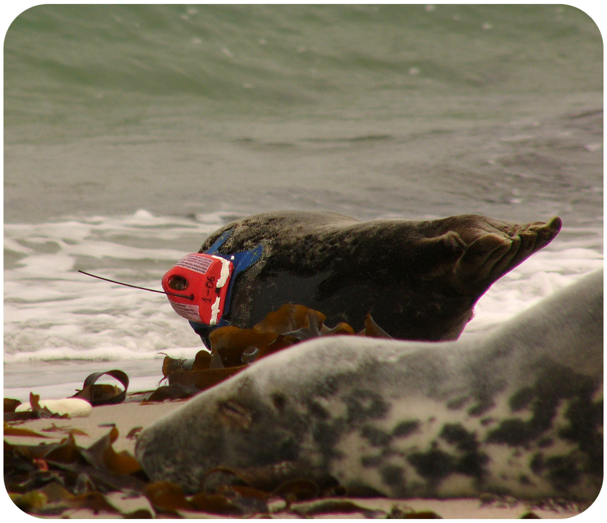


Figure 1.19: A radiotelemetry device used to track the movement of seals in the wild.

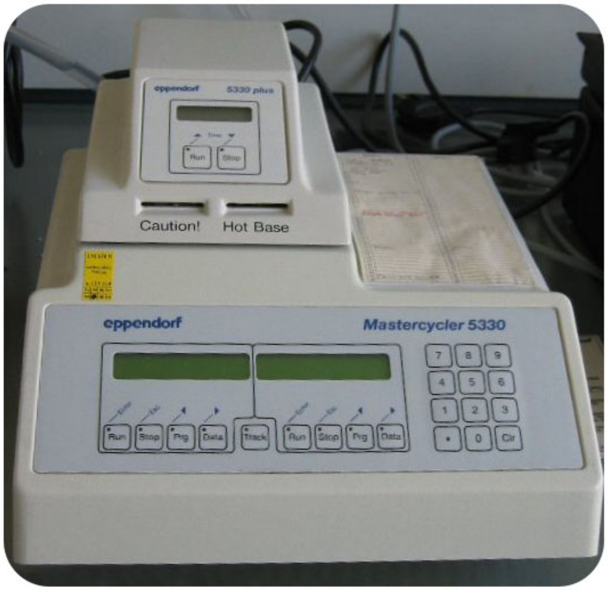


Figure 1.20: A thermocycler used for molecular biological and genetic studies.

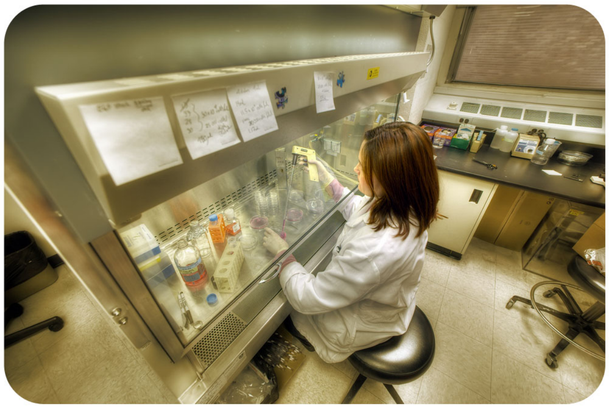


Figure 1.21: A sterile laboratory chamber. This laboratory inoculation hood allows researchers to conduct experiments in sterile environments.

Using Maps and Other Models

People use models for many purposes. We use street maps to help us find our way around. A model of the solar system may show the relationship between the planets in space. Life scientists often use maps to show where different organisms live, or to learn about the climate of an area. Scientists use maps and models to explain observations and to make predictions. For example, if a scientist wants to study the effect of temperature on coral reefs, he or she would first consult a map of coral reef locations and then measure the temperature in those specific areas (**Figure** 1.22).

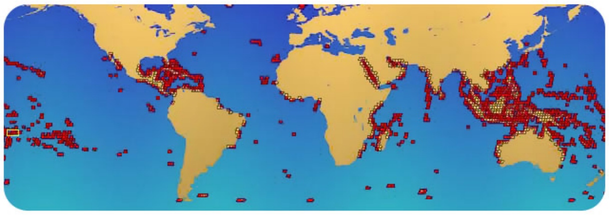


Figure 1.22: The above map shows where you can find coral reefs around the world. Coral reefs are shown in red.

Some models are used to show the relationship between different parts of an experiment, or variables. For example, the model in **Figure** 1.23 says that when there are few coyotes, there are many rabbits (left side of the graph) and when there are only a few rabbits, there are many coyotes (right side of the graph). You could make a prediction, based on this model, that removing all the coyotes from the ecosystem would result in an increase in rabbits. This is a good scientific prediction because it can be tested.

Lesson Summary

- From the time that the first microscope was built, over four hundred years ago, microscopes have been used to make major discoveries.
- Life science is a vast field; different kinds of research usually require very different tools.
- Scientists use maps and models to understand how features of real events or processes work.

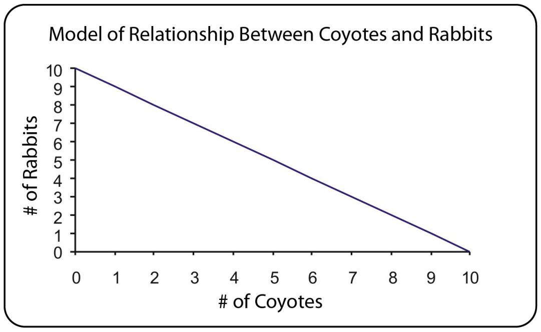


Figure 1.23: This graph shows a model of a relationship between a population of coyotes (the predators) and a population of rabbits, which the coyotes eat (the prey).

Review Questions

Recall

1. What did van Leeuwenhoek discover when he looked at scum from his own teeth under the microscope?
2. What does the symbol 10X on the side of a microscope mean?
3. What is a scientific model?

Apply Concepts

4. Look at the predator/prey (coyote/rabbit) model in **Figure** 1.23. What does the model predict would happen to the rabbit population if you took away all of the coyotes?

Think Critically

5. If you want to describe all of the places on the planet where ants can survive, how would you display this information?

6. What tool might you use to keep track of where a wolf travels?

Points to Consider

- What hazards may biologists face in the laboratory?
- What could be risks may biologists face who complete research outside?
- What do you think biologists do to protect themselves?

1.5 Safety in Scientific Research

Lesson Objectives

- Recognize how the kind of hazards that a scientist faces depends on the kind of research they do.
- Identify some potential risks associated with scientific research.
- Identify how safety regulations protect scientists and the environment.

Vocabulary

- biohazard
- carcinogen
- field scientist
- teratogen

Types of Safety Hazards

There are some very serious safety risks in scientific research. When studying a science like chemistry, scientists need to make sure that they do not mix two explosive chemicals together. Since the life sciences deal with living organisms, some research may have risks not found in other fields. Safety practices must be followed when working with the following hazardous things:

- Disease-causing viruses, bacteria or fungi
- Parasites
- Wild animals
- Radioactive materials
- Pollutants in air, water, or soil
- Toxins
- Teratogens
- Carcinogens
- Radiation

The kinds of risks that scientists face depend on the kind of research they perform. For example, a bacteriologist working with bacteria in a laboratory faces different risks than a zoologist studying the behavior of lions in Africa.

Think back to the deformed frogs discussed earlier. If there is something in the frogs' environment causing these deformities, could there be a risk to a researcher in that environment? A chemical in the pond that could cause such deformities is called a **teratogen**. If the chemical is causing deformities in frogs, could it cause deformities in humans? A scientist would most likely wear gloves and maybe even a mask when dealing with polluted water.

Or perhaps a disease is causing the deformities. Viruses and bacteria are called **biohazards. Figure** 1.24 shows laboratory safety and chemical hazard signs. Biohazards include any biological material that could make someone sick. A used needle or laboratory bacteria are also biohazards.

Laboratory Safety

If you perform an experiment in your classroom, your teacher will explain how to be safe. Professional scientists follow safety rules as well, especially for the study of dangerous organisms like the bacteria that

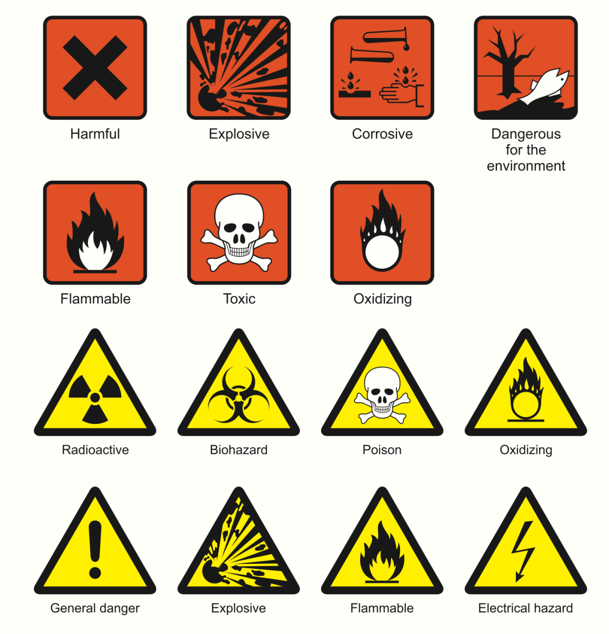


Figure 1.24: Science Laboratory Safety and Chemical Hazard Signs.

cause bubonic plague, as shown in **Figure** 1.25.

Sharp objects, chemicals, heat, and electricity are all used at times in laboratories. Below is a list of safety guidelines that you should follow when doing labs:

- Be sure to obey all safety guidelines given in lab instructions and your teacher.
- Follow directions carefully.
- Tie back long hair.
- Wear closed shoes with flat heels and shirts with no hanging sleeves, hoods, or drawstrings.
- Use gloves, goggles, or safety aprons when instructed to do so.
- Broken glass should only be cleaned up with a dust pan and broom. Never touch broken glass with your bare hands.
- Never eat or drink anything in the science lab. Table tops and counters could have dangerous substances on them.
- Be sure to completely clean materials like test tubes and beakers. Leftover substances could interact with other substances in future experiments.
- If you are using flames or heat plates, be careful when you reach. Be sure your arms and hair are kept far away from heat.
- Alert your teacher immediately if anything out of the ordinary occurs. An accident report may be required if someone is hurt and the lab supervisor must know if any materials are damaged or discarded.

Field Research Safety

Scientists who work outdoors, called **field scientists**, are also required to follow safety regulations designed to prevent harm to themselves, other humans, to animals, and the environment. In fact, if scientists work outside the country, they are required to learn about and follow the laws and restrictions of the country

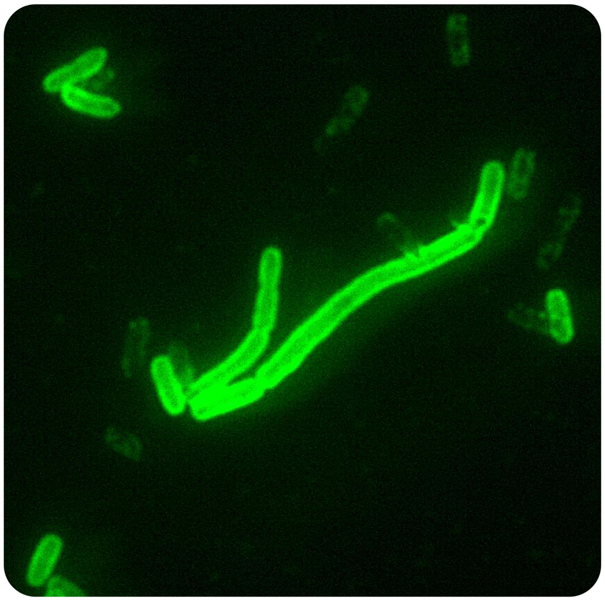


Figure 1.25: Scientists studying dangerous organisms such as , the cause of bubonic plague, use special equipment that helps keep the organism from escaping the lab.

in which they are doing research. For example, entomologists following monarch butterfly (**Figure** 1.26) migrations between the United States and Mexico must follow regulations in both countries.

Figure 1.26: A Monarch Butterfly

Field scientists are also required to follow laws to protect the environment. Before biologists can study protected wildlife or plant species, they must apply for permission to do so, and obtain a research permit. For example, if scientists collect butterflies without a permit, they may unknowingly disturb the balance of the organism's habitat.

Lesson Summary

- Research of any kind may have safety risks. Because life scientists study organisms as diverse as bacteria and bears, they deal with risks that other scientists may never encounter.
- The risks scientists face depend on the kind of research they are doing.
- Scientists are required by federal, state, and local institutions to follow strict regulations designed to

protect the safety of themselves, the public, and the environment.

Review Questions

Recall

1. What kinds of hazards might be found in biology laboratories, but not physics laboratories?
2. Who has more freedom to do whatever research they want? Laboratory scientists or field biologists?
3. What is a biohazard?
4. What is a research permit?

Apply Concepts

5. What are some of the precautions you might take if you were collecting frogs in water you think might be polluted?

6. Name some possible hazards to field biologists.

Think Critically

7. You want to complete field research on the border between the United States and Mexico. Before you begin, what precautions should you take?

Further Reading / Supplemental Links

- Biosafety in Microbiological and Biomedical Laboratories (National Research Council, 1999).
- Chemical Classification Signs: `http://www.howe.k12.ok.us/~jimaskew/nfpa.htm`
- NFPA Chemical Hazard Labels: `http://www.atsdr.cdc.gov/NFPA/nfpa_label.html`
- Where to Find MSDS's on the Internet: `http://www.ilpi.com/msds/index.html`
- MSDS Power Point: `http://www.tenet.edu/teks/science/safety/pdf/hazcom/msds.ppt` `http://www.research.northwestern.edu/ors/biosafe/index.htm`

Points to Consider

- What do you think makes something "alive?"
- What does a blade of grass, a fly, and a human have in common?

Chapter 2

MS What is a Living Organism?

How do we tell the difference between a living thing and a non-living thing? Think about your own body. How do you know that you are alive? Your heart beats. You breathe in air. Do all living things need to do be like you in order to be ”alive”?

The above image represents bacteria. Do these bacteria look like they could be alive? They do not have hands or feet or a heart or a brain, but they are actually more similar to you than you may think. Scientists found that all living things share certain characteristics. In this chapter, we will discover how to precisely define living things.

2.1 Characteristics of Living Organisms

Lesson Objectives

- List the defining characteristics of living things.
- List the needs of all living things.

Vocabulary

- cell
- embryo
- homeostasis
- organism

Characteristics of Life

How do you define a living thing? What do mushrooms, daisies, cats, and bacteria have in common? All of these are living things, or **organisms**. It might seem hard to think of similarities among such different organisms, but they actually have many things in common. Living things are similar to each other because all living things evolved from the same common ancestor that lived billions of years ago. See `http://vimeo.com/16794275` for a powerful introduction to life.

All living organisms:

1. Need energy to carry out life processes.
2. Are composed of one or more cells.
3. Respond to their environment.
4. Grow and reproduce.
5. Maintain a stable internal environment (**homeostasis**).

Living Things Need Resources and Energy

Why do you eat everyday? To get energy. The work you do each day, from walking to writing and thinking, is fueled by energy. But you are not the only one. In order to grow and reproduce, all living things need energy. But where does this energy come from?

The source of energy differs for each type of living thing. In your body, the source of energy is the food you eat. Here is how animals, plants and fungi obtain their energy:

- All animals must eat plants or other animals in order to obtain energy and building materials.
- Plants don't eat. Instead, they use energy from the sun to make their "food" through the process of photosynthesis.
- Mushrooms and other fungi obtain energy from other organisms. That's why you often see fungi growing on a fallen tree; the rotting tree is their source of energy (**Figure** 2.1).

Since plants harvest energy from the sun and other organisms get their energy from plants, nearly all the energy of living things initially comes from the sun.

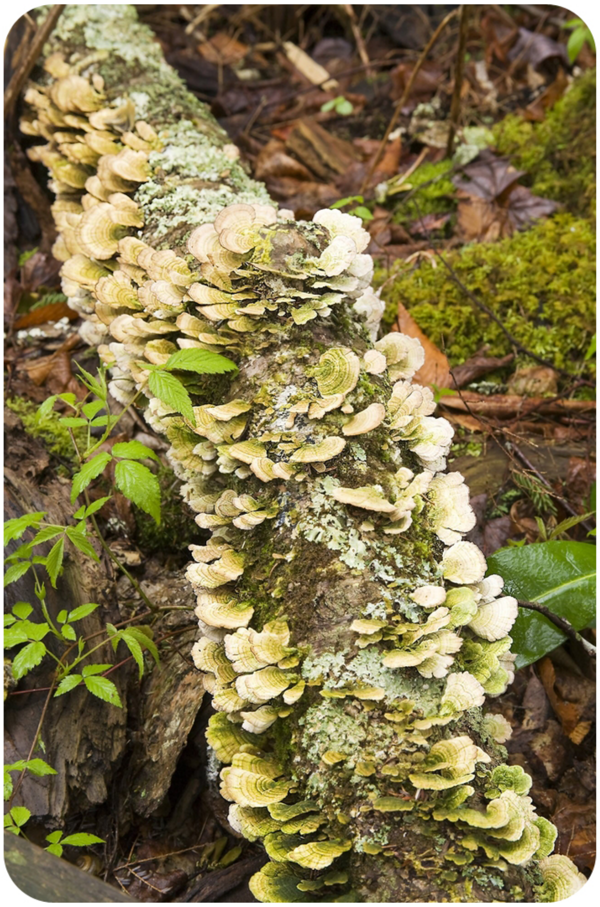


Figure 2.1: Bracket fungi and lichens on a rotting log in Cranberry Glades Park near Marlinton, West VIrginia. Fungi obtain energy from breaking down dead organisms, such as this rotting log.

Living Things Are Made of Cells

If you zoom in very close on the skin on your hand, you will find cells (**Figure** 2.3). **Cells** are the smallest unit of living things. Most cells are so small that they are usually visible only through a microscope. Some organisms, like bacteria, plankton that live in the ocean, or the paramecium shown in **Figure** 2.4 are made of just one cell. Other organisms have millions of cells. On the other hand, eggs are some of the biggest cells around. A chicken egg is just one huge cell.

The Inner Life of the Cell can be viewed at `http://www.youtube.com/watch?v=Mszlckmc4Hw` (5:28).

Figure 2.2: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/588

All cells share at least some structures. Although the cells of different organisms are built differently, they all function much the same way. Every cell must get energy from food, be able to grow and reproduce, and respond to its environment.

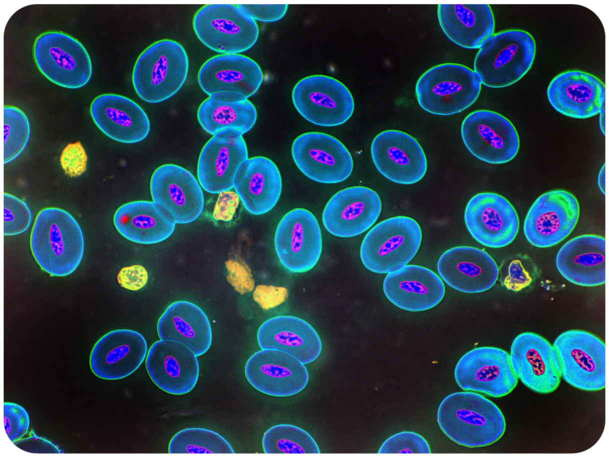


Figure 2.3: Reptilian blood cell showing the characteristic nucleus. A few smaller white blood cells are visible. This image has been magnified 1000 times its real size.

Living Things Respond to their Environment

All living things are able to react to something important or interesting in their external environment. For example, living things respond to changes in light, heat, sound, and chemical and mechanical contact. Organisms have means for receiving information, such as eyes, ears, and taste buds.

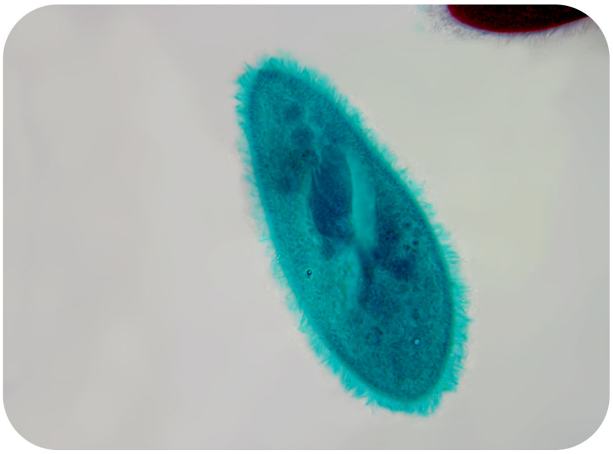


Figure 2.4: This paramecium is a single-celled organism.

Living Things Grow and Reproduce

All living things reproduce to make the next generation. Organisms that do not reproduce will go extinct. As a result, there are no species that do not reproduce (**Figure** 2.5).

Figure 2.5: Like all living things, cats reproduce themselves and make a new generation of cats. When animals and plants reproduce they make tiny undeveloped versions of themselves called , which grow up and develop into adults. A kitten is a partly developed cat.

Living Things Maintain Stable Internal Conditions

When you are cold, what does your body do to keep warm? You shiver to warm up your body. When you are too warm, you sweat to release heat. When any living thing gets thrown off balance, its body or cells help them return to normal. In other words, living things have the ability to keep a stable internal environment. Maintaining a balance inside the body or cells of organisms is known as **homeostasis**. Like us, many animals have evolved behaviors that control their internal temperature. A lizard may stretch out on a sunny rock to increase its internal temperature, and a bird may fluff its feathers to stay warm (**Figure** 2.6).

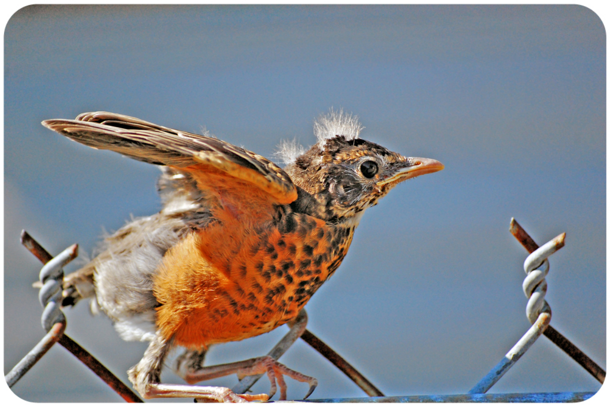


Figure 2.6: A bird fluffs his feathers to stay warm (keep from losing energy) and to maintain homeostasis.

Lesson Summary

- All living things grow, reproduce, and maintain a stable internal environment.
- All organisms are made of cells.
- All living things need energy and resources to survive.

Review Questions

Recall

1. Define the word organism.
2. What are three characteristics of living things?

Apply Concepts

3. What are a few ways organisms can get the energy they require?
4. What is a cell?

Think Critically

5. Think about fire. Can fire be considered a living thing? Why or why not?

Points to Consider

- DNA is considered the ”instructions” for the cell. What do you think this means?
- What kinds of chemicals do you think are necessary for life?
- Do you expect that the same chemicals can be in non-living and living things?

2.2 Chemicals of Life

Figure 2.7: Life on a rocky peak in the Waitakere Ranges.

Lesson Objectives

- Define matter, element, and atom.
- Name the four main classes of organic molecules that are building blocks of life.

Vocabulary

- atom
- atomic number
- carbohydrate
- chemical reaction
- compound
- electron
- element
- enzyme
- lipid
- macromolecule
- matter
- molecule
- neutron
- nucleic acid
- organic compound
- Periodic Table
- product
- protein
- proton
- reactant

=

Check Your Understanding

- What are the main properties of all living things?
- What is homeostasis?

The Elements

If you pull a flower petal from a plant and break it in half, and take that piece and break it in half again, and take the next piece, and break it half and so on and so on, until you cannot even see the flower anymore — what do you think you will find? Scientists have broken down **matter**, or anything that takes up space and has mass, into the smallest pieces that cannot be broken down anymore. Rocks, animals, flowers, and your body are all made up of matter (see 2.7).

Matter is made up mixture of things called elements. **Elements** are substances that cannot be broken down into simpler substances. There are more than 100 known elements, and 92 occur naturally around us. The others have been made only in the laboratory.

Inside of elements, you will find identical atoms. An **atom** is the simplest and smallest particle of matter that still has chemical properties of the element. Atoms are the building block of all of the elements that make up the matter in your body or any other living or non-living thing. Atoms are so small that only the most powerful microscopes can see them.

Each element has a different type of atom, and is represented with a one or two letter symbol. For example, the symbol for oxygen is O and the symbol for helium is He.

Atoms themselves are composed of even smaller particles, including positively charged **protons**, uncharged **neutrons**, and negatively charged **electrons**. Protons and neutrons are located in the center of the atom, or the nucleus, and the electrons move around the nucleus. How many protons an atom has determines what element it is. For example, Helium (He) always has two protons (**Figure** 2.8), while Sodium (Na) always has 11. All the atoms of a particular element have the exact same number of protons, and the number of protons is that element's **atomic number**.

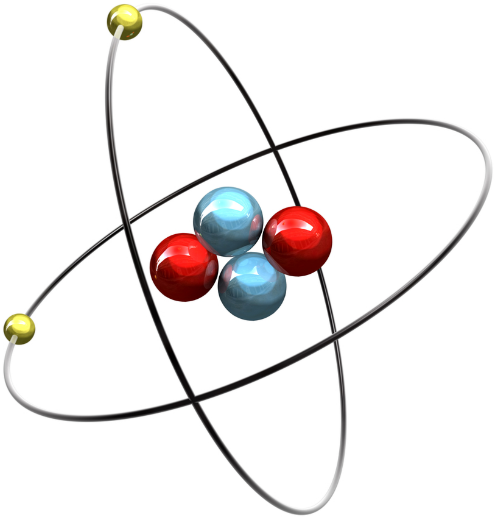


Figure 2.8: An atom of Helium (He) contains two positively charged protons (red), two uncharged neutrons (blue), and two negatively charged electrons (yellow).

The Element Song can be heard at `http://www.youtube.com/watch?v=DYW5OF42ss8` (1:25)

Figure 2.9: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/466

The Periodic Table

In 1869, a Russian scientist named Dmitri Mendeleev created the **Periodic Table**, which is a way of organizing elements according to their unique characteristics, like atomic number, density, boiling point, and other values (see **Figure** 2.10). Each element has a one or two letter symbol. For example, H stands for hydrogen and Au for gold. The vertical columns in the periodic table are known as groups, and elements in groups tend to have very similar properties. The table is also divided into rows, known as periods.

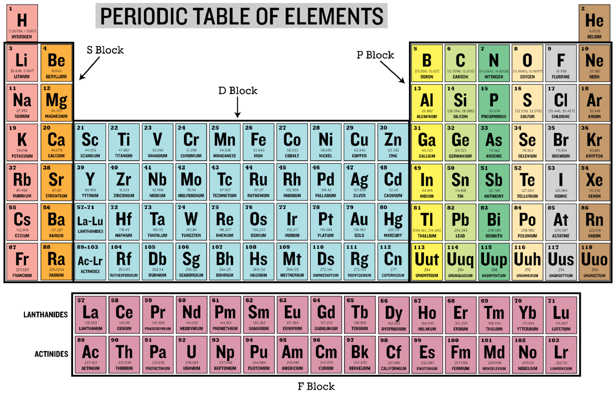


Figure 2.10: The periodic table groups the elements based on their properties.

Chemical Reactions

A **molecule** is any combination of two or more atoms. The oxygen in the air we breathe is two oxygen atoms connected by a chemical bond to form O_2, or molecular oxygen. A carbon dioxide molecule is a combination of one carbon atom and two oxygen atoms. Because carbon dioxide includes two different elements it is a compound as well as a molecule.

A **compound** is any combination of two or more elements. A compound has different properties from the elements that it contains. Elements and combinations of elements make up all the many types of matter in the universe. A **chemical reaction** is a process that breaks or forms the bonds between atoms.

For example, hydrogen and oxygen bind together to form water. The molecules that come together to start a chemical reaction are the **reactants**. So hydrogen and oxygen are reactants. The **product** is the end result of a reaction. In this example, water is the product.

Organic Compounds

The chemical components of living organisms are known as **organic compounds**. Organic compounds are molecules built around the element carbon (C). Living things are made up of very large molecules. These large molecules are called **macromolecules** because ”macro” means large. Our body gets the organic molecules we need from the food we eat (**Figure** 2.11). Which organic molecules do you recognize from the list below?

The four main macromolecules found in living things, shown in **Table** 2.1, are:

1. Proteins
2. Carbohydrates
3. Lipids
4. Nucleic Acids

What are proteins and what do they do? can be seen at `http://ghr.nlm.nih.gov/handbook/howgeneswork/protein`. *What is DNA?* can be viewed at `http://ghr.nlm.nih.gov/handbook/basics/dna`.

Figure 2.11: A healthy diet includes protein, fat, and carbohydrate, providing us with organic molecules.

Table 2.1:

	Proteins	**Lipids**	**Carbohydrates**	**Nucleic Acids**
Elements	C,H,O,N,S	C,H,O	C,H,O,P	C,H,O,P,N
Examples	Enzymes, muscle fibers, antibodies	Sugar, Starch, Glycogen, Cellulose	Phospholipids in membranes, fats, oils, waxes, steroids	DNA, RNA, ATP
Monomer (small building block molecule)	Amino acids	Often include fatty acids	Often include fatty acids	Nucleotides

The *Molecules of Cells,* an overview of the molecules of the cell, can be viewed at `http://www.youtube.com/watch?v=Q1dRmbCCO4Y&#38;feature=fvw` (6:09).

Figure 2.12: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/589

Carbohydrates

Carbohydrates are sugars or long chains of sugars. An important role of carbohydrates is to store energy. Glucose (**Figure** 2.13 is a simple sugar molecule with the chemical formula $C_6H_{12}O_6$.

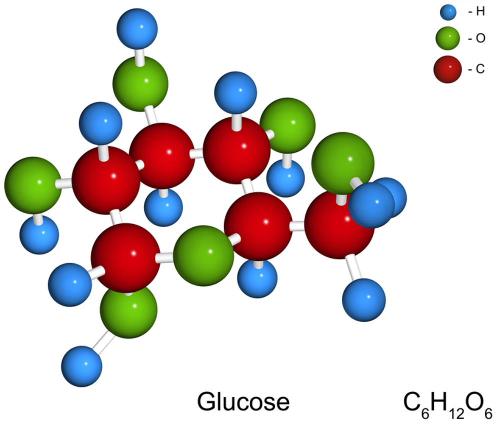


Figure 2.13: A molecule of glucose (a carbohydrate).

Carbohydrates also include long chains of connected sugar molecules. Plants store sugar in long chains called starch, whereas animals store sugar in long chains called glycogen. You get the carbohydrates you need for energy from eating carbohydrate-rich foods, including fruits and vegetables, as well as grains, such as bread, rice, or corn.

Proteins

Proteins are molecules that have many different functions in living things. All proteins are made of small molecules called amino acids that connect together like beads on a necklace (**Figure** 2.14) and **Figure** 2.16). There are only 20 common amino acids needed to build proteins. These amino acids form in thousands of different combinations, making 100,000 or more unique proteins in humans. Proteins can differ in both the number and order of amino acids. Small proteins have just a few hundred amino acids. The largest proteins have more than 25,000 amino acids.

Many important molecules in your body are proteins. **Enzymes** are a type of protein that speed up chemical reactions. For example, your stomach would not be able to break down food if it did not have special enzymes to speed up the rate of digestion. Antibodies that protect you against disease are proteins. Muscle fiber is mostly protein (**Figure** 2.15).

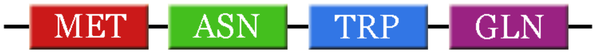


Figure 2.14: Amino Acids connect together like beads on a necklace.

Figure 2.15: Muscle fibers are made mostly of protein.

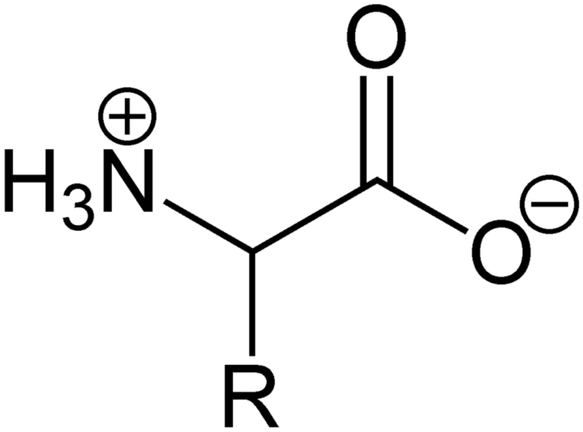


Figure 2.16: General Structure of Amino Acids. This model shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. KEY: H = hydrogen, N = nitrogen, C = carbon, O = oxygen, R = variable side chain.

It's important for you and other animals to eat food with protein because we cannot make some amino acids ourselves. You can get proteins from plant sources, such as beans, and from animal sources, like milk or meat. When you eat food with protein, your body breaks the proteins down into individual amino acids and uses them to build new proteins. You really are what you eat!

Lipids

Have you ever tried to put oil in water? They don't mix. Oil is a type of lipid. **Lipids** are molecules such as fats, oils, and waxes. The most common lipids in your diet are probably fats and oils. Fats are solid at room temperature, whereas oils are fluid. Animals use fats for long-term energy storage and to keep warm. Plants use oils for long-term energy storage. When preparing food, we often use animal fats, such as butter, or plant oils, such as olive oil or canola oil.

There are many more type of lipids that are important to life. One of the most important are the phospholipids (see the chapter titled *Cell Functions*) that make up the protective outer membrane of all cells (**Figure** 2.17).

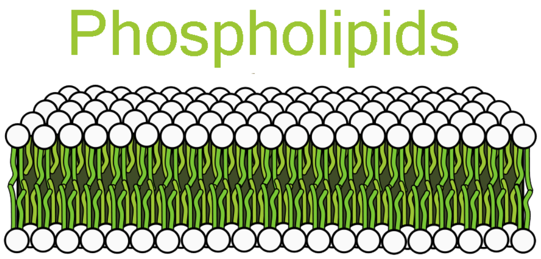


Figure 2.17: Phospholipids in a membrane.

Nucleic acids

Nucleic acids are long chains of nucleotides. Nucleotides are made of a sugar, a nitrogen-containing base, and a phosphate group. Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are the two main nucleic acids. DNA is the molecule that stores our genetic information (**Figure** 2.18). RNA is involved in making proteins. ATP (adenosine triphosphate), known as the "energy currency" of the cell, is also a nucleic acid. See the National Institutes of Health publication *The New Genetics* (`http://publications.nigms.nih.gov/thenewgenetics)` for further information.

An overview of DNA can be seen at `http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/4/_-vZ_g7K6P0`.

Arsenic in Place of Phosphorus?

In late 2010, scientists proposed that the notion that the elements essential for life - carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur - may have additional members. Scientists have trained a bacterium to eat and grow on a diet of arsenic, in place of phosphorus. Phosphorus chains form the backbone of DNA, and ATP is the principal molecule in which energy in the cell is stored. Arsenic is directly under phosphorus in the Periodic Table, so the two elements have similar chemical bonding properties. This

Figure 2.18: DNA, a nucleic acid.

Figure 2.19: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/101

finding raises the possibility that organisms could exist on Earth or elsewhere in the universe using biochemicals not currently known to exist. These results will expand the notion of what life could be and where it could be. It could be possible that life on other planets may have formed using biochemicals with other elements.

See `http://www.nytimes.com/2010/12/03/science/03arsenic.html?pagewanted=1&#38;_r=3` for further information.

Lesson Summary

- Elements are substances that cannot be broken down into simpler substances with different properties.
- Elements have been organized by their properties to form the periodic table.
- Two or more atoms can combine to form a molecule.
- Molecules consisting of more than one element are called compounds.
- Reactants can combine through chemical reactions to form products.
- Enzymes can speed up a chemical reaction.
- Living things are made of just four classes of macromolecules: proteins, carbohydrates, lipids, and nucleic acids.

Review Questions

Recall

1. What are the 4 main classes of organic compounds?

2. Sugar is what kind of organic compound?
3. What is an atom?
4. Name a few examples of proteins.
5. Name a few examples of lipids in organisms.
6. What are two nucleic acids?

Apply Concepts

7. Would water, with the symbol H_2O, be considered an element or a compound?
8. How many types of atoms make up gold?

Think Critically

9. Why do you think you need fats in your diet?

Points to Consider

- Do you expect the genetic information in the DNA of a cow to be the same or different from that in a crow?
- If we are all composed of the same chemicals, how do all organisms look so different?
- What characteristics would you use to distinguish and classify living things?

2.3 Classification of Living Things

Lesson Objectives

- Explain what makes up a scientific name.
- Explain what defines a species.
- List the information scientists use to classify organisms.
- List the three domains of life and the chief characteristics of each.

Check Your Understanding

- What are the basic characteristics of life?
- What are the four main classes of organic molecules that are building blocks of life?

Vocabulary

- Archaea
- bacteria
- binomial nomenclature
- classify
- domain
- Eukarya
- genus
- species
- taxonomy

Classifying Organisms

When you see an organism that you have never seen before, you probably put it into a group without even thinking. If it is green and leafy, you probably call it a plant. If it is long and slithers, you probably call it as a snake. How do you make these decisions? You look at the physical features of the organism and think about what it has in common with other organisms.

Scientists do the same thing when they **classify**, or put in categories, living things. Scientists classify organisms not only by their physical features, but also by how closely related they are. Lions and tigers look like each other more than they look like bears. It turns out that the two cats are actually more closely related to each other than to bears. How an organism looks and how it is related to other organisms determines how it is classified.

Linnaean system of classification

People have been concerned with classifying organisms for thousands of years. Over 2,000 years ago, the Greek philosopher Aristotle developed a classification system that divided living things into several groups that we still use today, including mammals, insects, and reptiles.

Carl Linnaeus (1707-1778) (**Figure** 2.20) built on Aristotle's work to create his own classification system. He invented the way we name organisms today. Linnaeus is considered the inventor of modern **taxonomy**, the science of naming and grouping organisms. See `http://www.ucmp.berkeley.edu/history/linnaeus.html` for additional information.

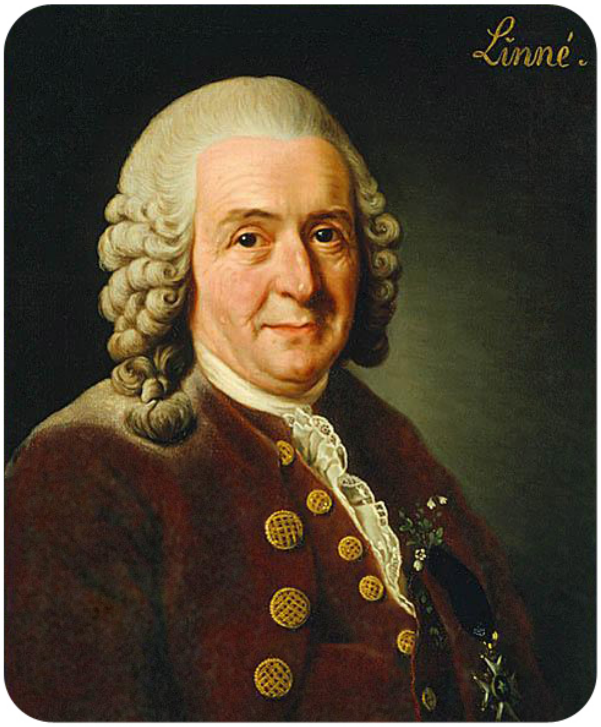


Figure 2.20: In the 18 century, Carl Linnaeus invented the two-name system of naming organisms (genus and species) and introduced the most complete classification system then known.

Linnaeus developed **binomial nomenclature**, a way to give a scientific name to every organism. Each species receives a two-part name in which the first word is the **genus** (a group of species) and the second word refers to one species in that genus. For example, a coyote's species name is *Canis latrans*. *Latrans* is the species and *canis* is the genus, a larger group that includes dogs, wolves, and other dog-like animals.

Here is another example: the red maple, *Acer rubra*, and the sugar maple, *Acer saccharum*, are both in the same genus and they look similar (**Figure** 2.21, **Figure** 2.22, and **Figure** 2.23). Notice that the genus is capitalized and the species is not, and that the whole scientific name is in italics. The names may seem strange, but they are written in a language called Latin.

Modern Classification

Modern taxonomists have reordered many groups of organisms since Linnaeus. The main categories that biologists use are listed here from the most specific to the least specific category (**Figure** 2.24). See `http://www.pbs.org/wgbh/nova/orchid/classifying.html` for further information.

- Least Specific
    - Domain
    - Kingdom
    - Phylum
    - Class
    - Order

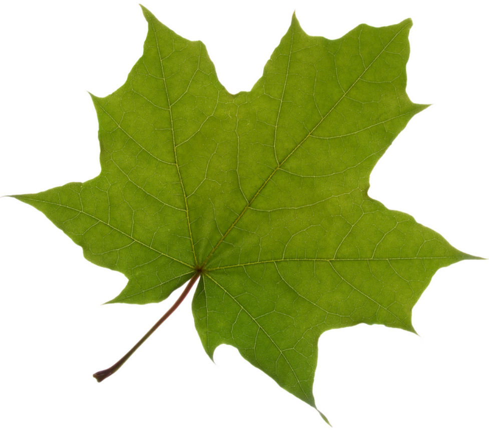


Figure 2.21: These leaves are from one of two different species of trees in the Acer, or maple, genus.

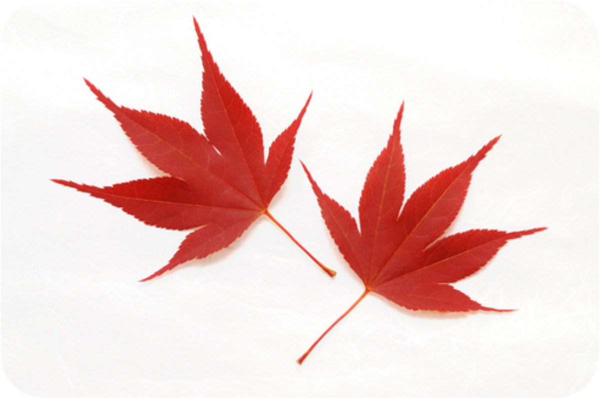


Figure 2.22: These leaves are from one of two different species of trees in the Acer, or maple, genus.

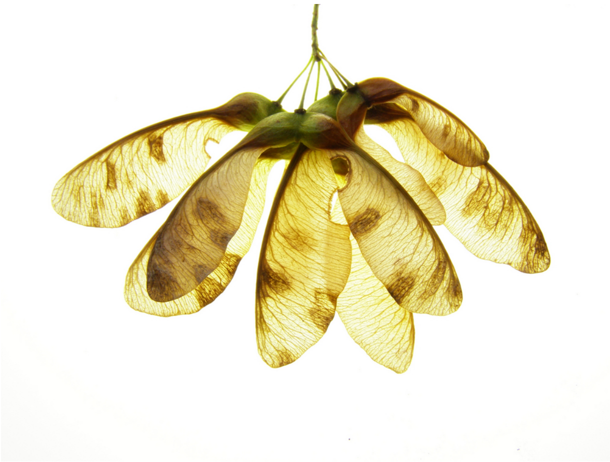


Figure 2.23: One of the characteristics of the maple genus is winged seeds.

  - Family
  - Genus
  - Species
- Most Specific

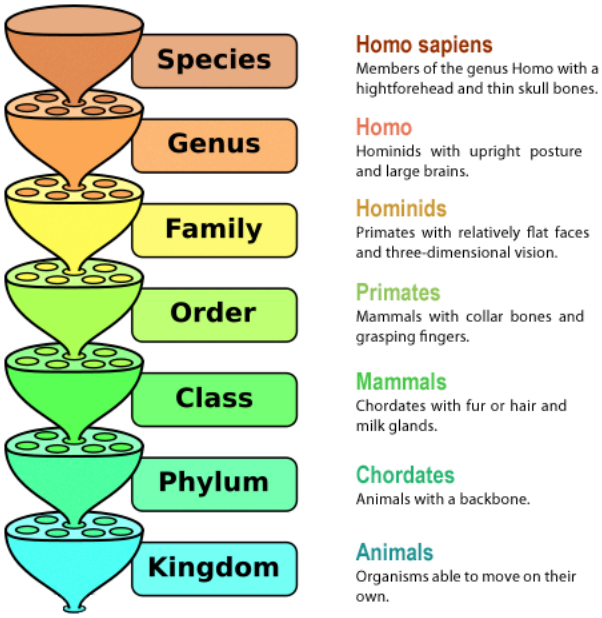

Species
Genus
Family
Order
Class
Phylum
Kingdom
Homo sapiens
Members of the genus Homo with a hightforehead and thin skull bones.
Homo
Hominids with upright posture and large brains.
Hominids
Primates with relatively flat faces and three-dimensional vision.
Primates
Mammals with collar bones and grasping fingers.
Mammals
Chordates with fur or hair and milk glands.
Chordates
Animals with a backbone.
Animals
Organisms able to move on their own.

Figure 2.24: This diagram illustrates the classification categories for organisms, with the broadest category (Kingdom) at the bottom, and the most specific category (Species) at the top.

The *Classification Rap* can be heard at `http://www.youtube.com/watch?v=6jAGOibTMuU` (3:18).

Figure 2.25: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/590

Difficulty Naming Species

Even though naming species is straightforward, deciding if two organisms are the same species can sometimes be difficult. Linnaeus defined each species by the distinctive physical characteristics shared by these organisms. But two members of the same species may look quite different. For example, people from different parts of the world sometimes look very different, but we are all the same species (**Figure** 2.26).

So how is a species defined? A **species** is group of individuals that can interbreed with one another and produce fertile offspring; a species does not interbreed with other groups. By this definition, two species of animals or plants that do not interbreed are not the same species. See *Biological Classification of Organisms* for additional information: `http://www.physicalgeography.net/fundamentals/9b.html`.

Figure 2.26: These children are all members of the same species, Homo sapiens.

Domains of Life

Let's explore the least specific category of classification, called a **domain**.

All of life can be divided into 3 domains, which tell you the type of cell inside of an organism:

1. **Bacteria**: Single-celled organisms that do not contain a nucleus
2. **Archaea**: Single-celled organisms that do not contain a nucleus; have a different cell wall from bacteria
3. **Eukarya**: Organisms with cells that contain a nucleus.

Archaea and Bacteria

Archaea and Bacteria (**Figure** 2.27 and **Figure** 2.28) seem very similar, but they also have significant differences.

Similarities:

- Do not have a nucleus
- Small cells
- One-celled
- Can reproduce without sex by dividing in two

Differences:

- Cell walls made of different material
- Archaea often live in extreme environments like hot springs, geysers, and salt flats while bacteria can live almost everywhere.

Eukarya

All of the cells in the domain Eukarya keep their genetic material, or DNA, inside the nucleus. The domain Eukarya is made up of four kingdoms:

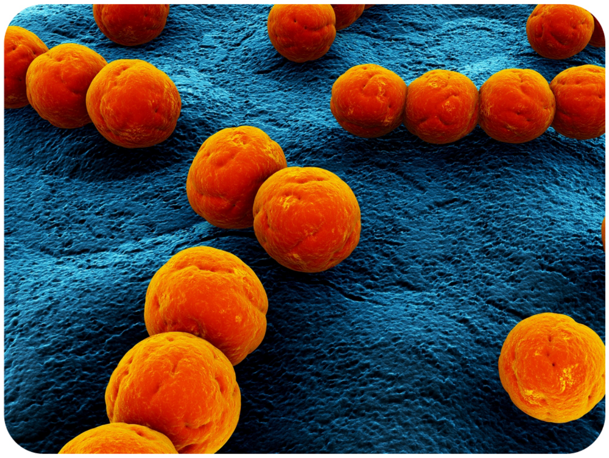


Figure 2.27: The Group D Streptococcus organism is in the domain Bacteria, one of the three domains of life.

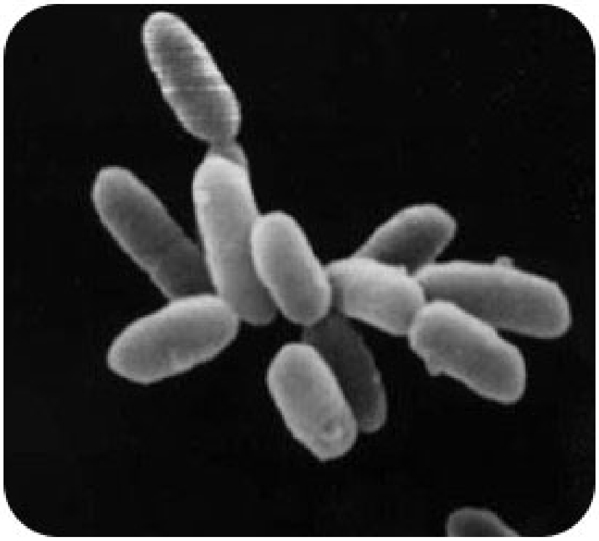


Figure 2.28: The Halobacterium is in the domain Archaea, one of the three domains of life.

1. Plantae: Plants, such as trees and grasses, survive by capturing energy from the sun, a process called photosynthesis.
2. Fungi: Fungi, such as mushrooms and molds, survive by ”eating” other organisms or the remains of other organisms.
3. Animalia: Animals survive by eating other organisms or the remains of other organisms. Animals range from tiny worms to insects, dogs, and the largest dinosaurs and whales (**Figure** 2.29).
4. Protista: Protists are not all descended from a single common ancestor in the way that plants, animals, and fungi are. Protists are all the eukaryotic organisms that do not fit into one of the other three kingdoms. They include many kinds of microscopic one-celled organisms, such as algae and plankton, but also giant seaweeds that can grow to be 200 feet long (an alga protist is shown in **Figure** 2.30).

Plants, animals, fungi, and protists might seem very different, but remember that if you look through a microscope, you will find similar cells with a membrane-bound nucleus in all of them. The main characteristics of the three domains of life are summarized in **Table** 2.2.

Figure 2.29: The Western Gray Squirrel is in the domain Eukarya, one of the three domains of life.

Table 2.2:

	Archaea	**Bacteria**	**Eukarya**
Multicelluar	No	No	Yes
Cell Wall	Yes, without peptidoglycan	Yes, with peptidoglycan	Varies. Plants and fungi have a cell wall; animals do not.
Nucleus (DNA inside a membrane)	No	No	Yes
Organelles inside a membrane	No	No	Yes

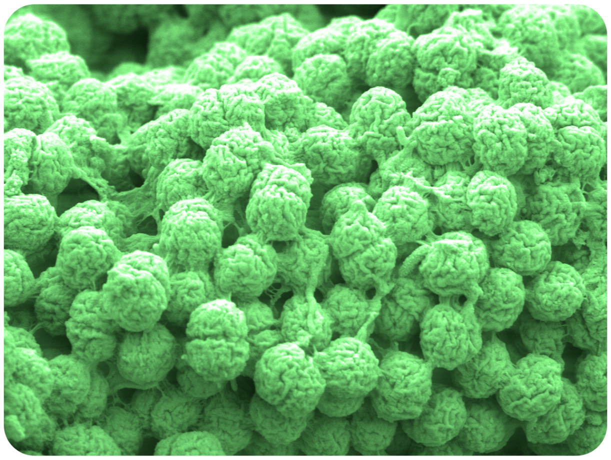


Figure 2.30: This microscopic alga is a protist in the domain Eukarya.

Viruses

We have all heard of viruses. The flu and many other diseases are caused by viruses. But what is a virus? Based on the material presented in this chapter, do you think viruses are living?

The answer is actually ”no.” A virus is essentially DNA or RNA surrounded by a coat of protein (**Figure** 2.31). It is not a cell and does not maintain homeostasis. Viruses also cannot reproduce on their own – they need to infect a host cell to reproduce. Viruses do, however, change over time, or evolve. So a virus is very different from any of the organisms that fall into the three domains of life.

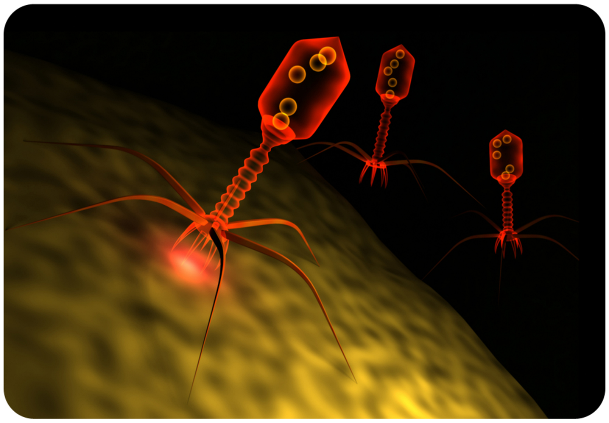


Figure 2.31: These ”moon lander” shaped viruses infects bacteria.

Lesson Summary

- Scientists have defined several major categories for classifying organisms: domain, kingdom, phylum, class, order, family, genus, and species.
- The scientific name of an organism consists of its genus and species.
- Scientists classify organisms according to their evolutionary histories and how related they are to one another - by looking at their physical features, the fossil record, and DNA sequences.
- All life can be classified into three domains: Bacteria, Archaea, and Eukarya.

Review Questions

Recall

1. Who designed modern classification and invented the two-part species name?
2. Define a species.
3. What kingdoms make up the domain Eukarya?
4. What is the name for the scientific study of naming and classifying organisms?
5. How are organisms given a scientific name?

Apply Concepts

6. In what domain are humans?
7. *Quercus rubra* is the scientific name for the red oak tree. What is the red oak's genus?
8. In what domain are mushrooms?
9. What information do scientists use to classify organisms?

Think Critically

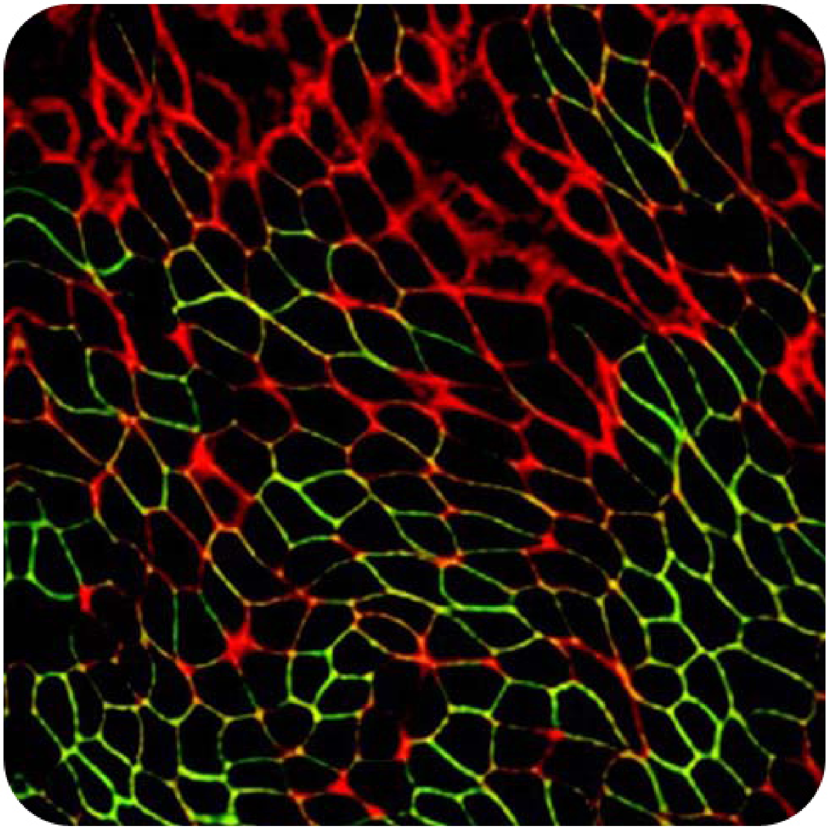
10. Is it possible for organisms in two different classes to be in the same genus?
11. If molecular data suggests that two organisms have very similar DNA, what does that say about their evolutionary relatedness?
12. Can two different species ever share the same scientific name?
13. If two organisms are in the same genus, would you expect them to look much alike?

Points to Consider

- This Section introduced the diversity of life on Earth. Do you think it is possible for cells from different organisms to be similar even though the organisms look different?
- Do you think human cells are different from bacterial cells?
- Do you think it is possible for a single cell to be a living organism?

Chapter 3

MS Cells and Their Structures



Look carefully at the above image. What do you see? What colors? What shapes? Can you guess what it is?

These are actually cells from a dog's kidney. Cells are the smallest units of living things. You are made of cells. Plants are made of cells. So are dogs, chickens, bees and mushrooms. Our cells even look very similar to the above dog cells.

But the cells of a kidney are not actually bright green and red. Scientists remove cells from organisms, dye them with different colors, and look at them under strong microscopes. The above image is an example of what scientists see under these microscopes. Now, we will explore what different types of cells look like and what they do.

3.1 Introduction to Cells

Lesson Objectives

- Explain how cells are observed.
- Define the three main parts of the cell theory.
- Explain the levels of organization in an organism.

Check Your Understanding

- What are the five main characteristics of living things?
- Name the four main classes of organic molecules that are building blocks of life.

Vocabulary

- organ
- organ system
- tissue

What are cells?

In the chapter *What is a Living Organism?*, you learned that living things are made of big molecules called proteins, lipids, carbohydrates, and nucleic acids. When these big molecules come together, they form a cell. A **cell** is the smallest unit of an organism that is still considered living (see the onion cells in **Figure** 3.1). Some organisms, like bacteria, consist of only one cell. Big organisms, like humans, consist of trillions of cells. Compare a human to a banana. On the outside, they look very different, but if you look close enough you'll see that their cells are actually very similar.

The Inner Life of the Cell can be viewed at `http://www.youtube.com/watch?v=Mszlckmc4Hw` (5:28).

Observing Cells

Most cells are so tiny that you cannot see them without the help of a microscope. It was not until 1665 that English scientist Robert Hooke invented a basic light microscope and observed cells for the first time. You may use light microscopes in the classroom. You can use a light microscope to see cells. But many structures in the cell are too small to see with a light microscope. So, what do you do if you want to see the tiny structures inside of cells?

In the 1950s, scientists developed more powerful microscopes. A light microscope sends a beam of light through a **specimen**, or the object you are studying. A more powerful microscope, called an **electron microscope**, passes a beam of electrons through the specimen. Sending electrons through a cell allows us to see its tiniest parts (**Figure** 3.3).

Without electron microscopes, we would not know what the inside of a cell looked like. The only problem with using an electron microscope is that it only works with dead cells. Scientists and students still use light microscopes to study living cells.

How to Correctly Use a Microscope can be viewed at `http://www.youtube.com/watch?v=jP9HtcAvGDk&#38;feature=related` (1:43).

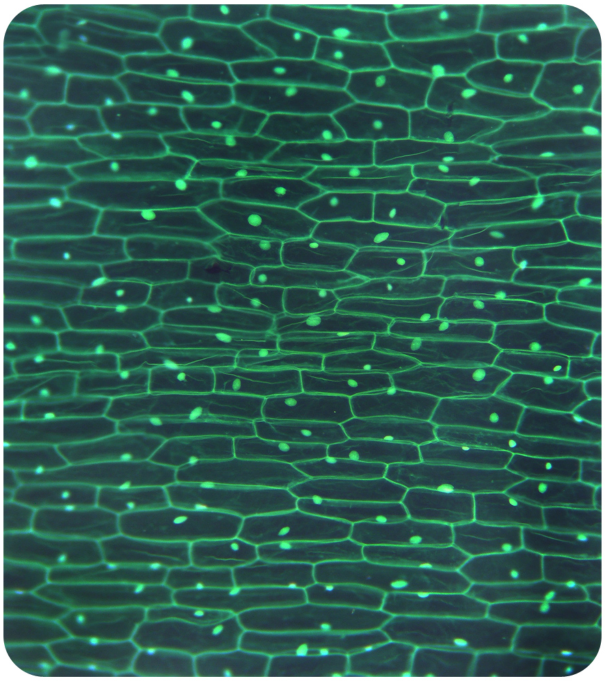


Figure 3.1: The outline of onion cells are visible under a light microscope.

Figure 3.2: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/588

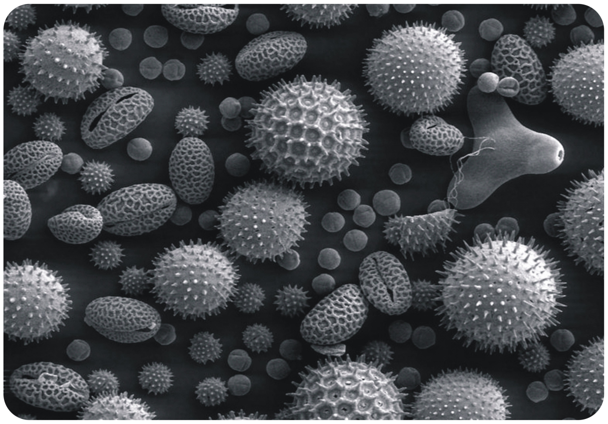


Figure 3.3: An electron microscope allows scientists to see much more detail than a light microscope, as with this sample of pollen. But a light microscope allows scientists to study living cells.

Video

Figure 3.4: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/591

Cell Theory

In 1858, after using microscopes much better than Hooke's first microscope, Rudolf Virchow developed the hypothesis that cells only come from other cells. For example, bacteria are composed of only one cell (**Figure** 3.5) and divide in half to make new bacteria. In the same way, your body makes new cells by dividing the cells you already have. In all cases, cells only come from cells that have existed before. This idea led to the development of one of the most important theories in biology, cell theory.

Cell theory states that:

1. All organisms are composed of cells.
2. Cells are alive and the basic living units of organization in all organisms.
3. All cells come from other cells.

As with other scientific theories, many hundreds, if not thousands, of experiments support the cell theory. Since Virchow created the theory, no evidence has ever contradicted it.

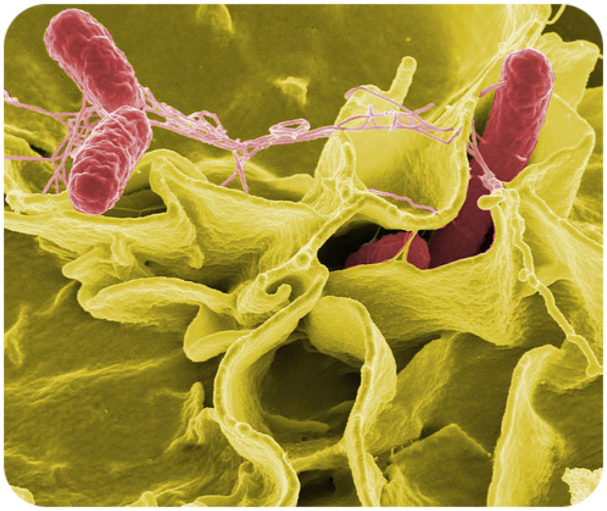


Figure 3.5: Bacteria (pink) are an example of an organism consisting of only one cell.

Levels of Organization

Although cells share many of the same features and structures, they also can be very different. Each cell in your body is designed for a specific task.

For example:

- Red blood cells (**Figure** 3.6) are shaped with a pocket that traps oxygen and brings it to other body cells.
- Nerve cells, which can quickly send the feeling of touching a hot stove to your brain, are long and stringy in order to form a line of communication with other nerve cells, like a wire (**Figure** 3.7).
- Skin cells (**Figure** 3.8) are flat and fit tightly together to protect your body.

An animation comparing the size of red blood cells and skin cells to other structures can be found at `http://learn.genetics.utah.edu/content/begin/cells/scale/.`

As you can see, cells are shaped in ways that help them do their jobs. Multicellular (many-celled) organisms have many types of specialized cells in their bodies.

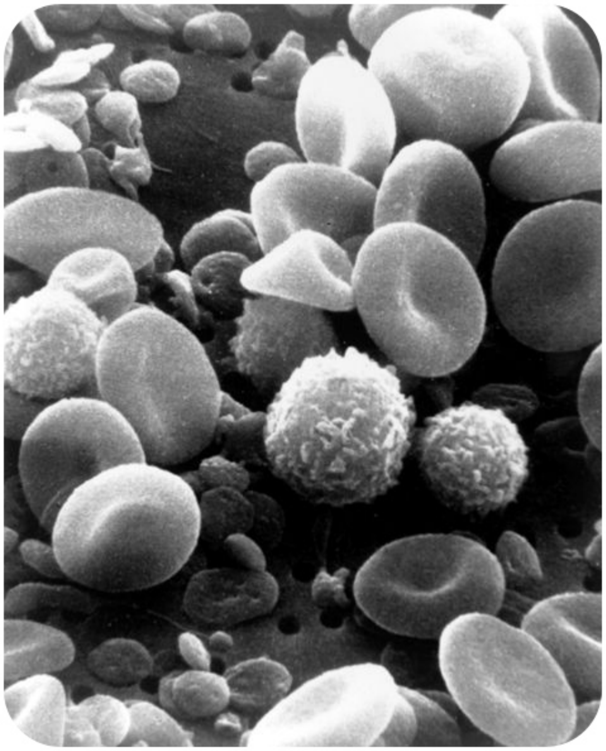


Figure 3.6: Red blood cells are specialized to carry oxygen in the blood.

While cells are the basic units of an organism, groups of cells can be specialized, or perform a specific job. Specialized cells can be organized into tissues. For example, your liver cells are organized into liver tissue, which is organized into an organ, your liver. Organs are formed from two or more specialized tissues working together to perform a job that helps your body work. All organs, from your heart to your liver, are made up of an organized group of tissues.

These organs are part of a larger system, the organ systems. For example, your brain works together with your spinal cord and other nerves to form the nervous system. This organ system must be organized with other organ systems, such as the circulatory system and the digestive system, for your body to work. Organ systems work together to form the entire organism. As you can see (**Figure** 3.9), there are many levels of organization in living things. See `http://www.schools.utah.gov/curr/science/sciber00/7th/cells/sciber/levelorg.htm` for additional information.

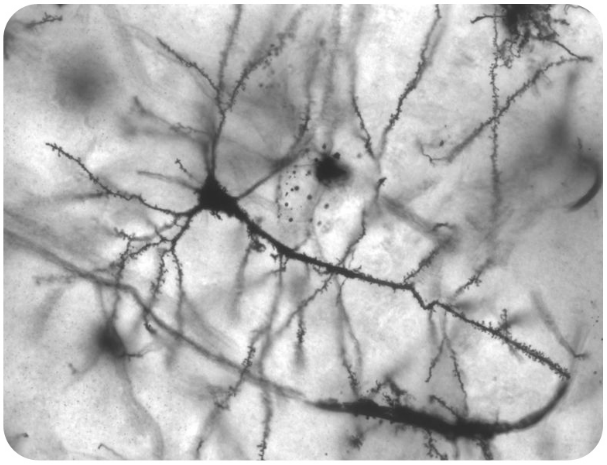


Figure 3.7: Neurons are shaped to conduct electrical impulses to many other nerve cells.

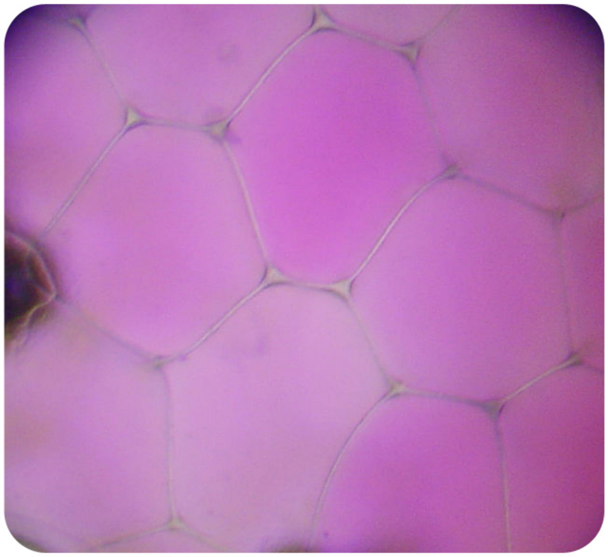


Figure 3.8: These epidermal cells make up the “skin” of plants. Note how the cells fit tightly together.

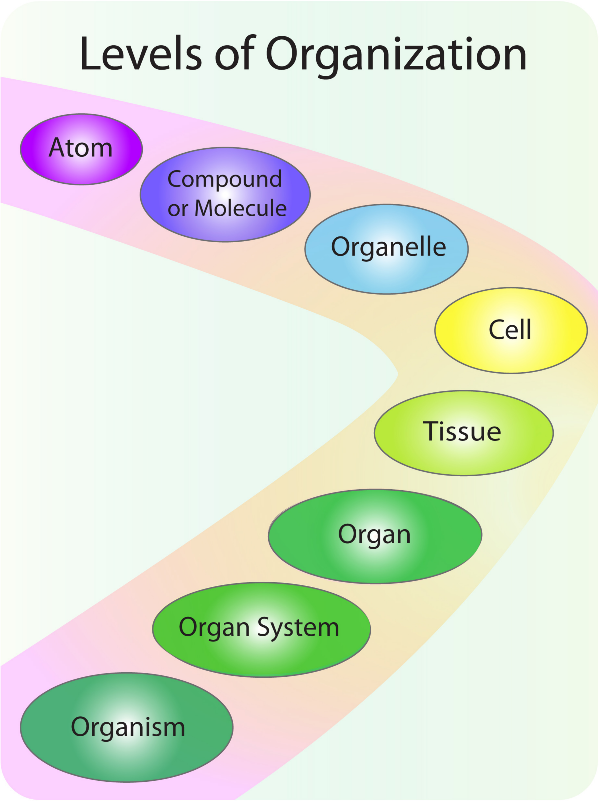


Figure 3.9: Levels of Organization, from the atom to the organism.

Lesson Summary

- Cells were first observed under a light microscope, but today's electron microscopes allow scientists to take a closer look at the inside of cells.
- Cell theory says that:
  - All organisms are composed of cells;
  - Cells are alive and the basic living units of organization in all organisms; and
  - All cells come from other cells.
- Cells are organized into tissues, which are organized into organs, which are organized into organ systems, which are organized to create the whole organism.

Review Questions

Recall

1. What scientific tool was used to first observe cells?
2. What are the three main parts of the cell theory?

Apply Concepts

3. Put the following in the correct order from simplest to most complex: organ, cell, tissue, organ system.

4. What type of microscope would be best for studying the structures found inside of cells?

Think Critically

5. According to the cell theory, can we create a new cell in laboratory by putting different molecules together? Why or why not?

Further Reading / Supplemental Links

- Baeuerle, Patrick A. and Landa, Norbert. *The Cell Works: Microexplorers.* Barron's; 1997, Hauppauge, New York.
- Sneddon, Robert. *The World of the Cell: Life on a Small Scale.* Heinemann Library; 2003, Chicago.
- Wallace, Holly. *Cells and Systems.* Heinemann Library; 2001, Chicago.

Points to Consider

- Do you think there would be a significant difference between bacterial cells and your brain cells? What might they be?
- Do you think a bacterial cell and a brain cell have some things in common? What might they be?
- Do you think cells have organs like we do? How would that benefit cells?

3.2 Cell Structures

Lesson Objectives

- Compare prokaryotic and eukaryotic cells.
- List the organelles of the cell and their functions.
- Discuss the structure and function of the cell membrane and cytosol.
- Describe the structure and function of the nucleus.
- Distinguish between plant and animal cells.

Check Your Understanding

- What is a cell?
- How do we visualize cells?

Vocabulary

- cell wall
- central vacuole
- chloroplast
- chromosome
- cytoplasm
- cytoskeleton
- cytosol
- endoplasmic reticulum (ER)
- eukaryote
- Golgi apparatus
- lysosome
- mitochondria
- nuclear envelope
- nucleus
- organelle
- plasma membrane
- prokaryote
- ribosome
- rough endoplasmic reticulum
- semipermeable
- smooth endoplasmic reticulum
- vesicle

Prokaryotic and Eukaryotic Cells

There are two basic types of cells, prokaryotic cells (**Figure** 3.10), found in organisms called **prokaryotes**, and eukaryotic cells (**Figure** 3.11), found in organisms called **eukaryotes**.

The main difference between eukaryotic and prokaryotic cells is that eukaryotic cells have a **nucleus**, where they store their DNA, or genetic material. The nucleus is membrane-bound, which means it is surrounded by a phospholipid membrane. Prokaryotic cells do not have a ”membrane-bound” nucleus. Instead, their

DNA floats around inside the cell.

Here are some other key features of eukaryotic cells:

1. They have membrane-bound structures called **organelles**. A list of the main eukaryotic organelles is located in **Table** 3.2.
2. Eukaryotic cells include the cells of fungi, animals, protists, and plants.
3. These cells are more specialized than prokaryotic cells.

Key features of prokaryotic cells include:

1. The cells are usually smaller and simpler than eukaryotic cells.
2. Prokaryotic cells do not have membrane-bound structures.
3. The DNA, or genetic material, forms a single large circle that coils up on itself.
4. Prokaryotic cells belong to the domains Bacteria or Archaea. These two domains were discussed in the *What is a Living Organism?* chapter.

From the above information, are the cells found in your body prokaryotic cells or eukaryotic cells? **Table** 3.1 compares prokaryotic and eukaryotic cells.

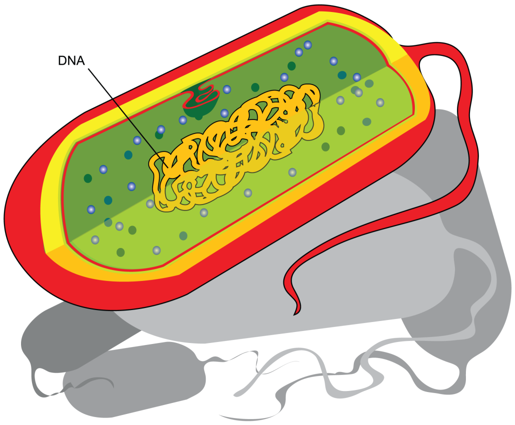


Figure 3.10: Prokaryotes do not have a nucleus. Instead, their genetic material is a simple loop of DNA.

Table 3.1: **Comparison of Prokaryotic and Eukaryotic Cells**

Feature	Prokaryotic cells	Eukaryotic cells
DNA	Single “naked” circle; plasmids	In membrane-enclosed nucleus
Membrane-enclosed organelles	No	Yes
Examples	Bacteria	Plants, animals, fungi

An *Introduction to Prokaryotic and Eukaryotic Cells* can be viewed at `http://www.youtube.com/watch?v=nP91ZG94D00` (2:13)

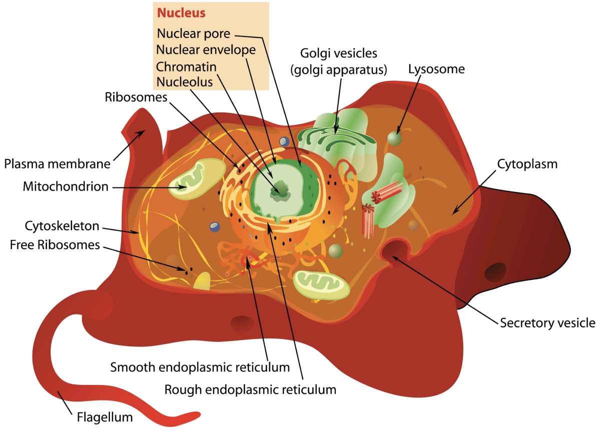


Figure 3.11: Eukaryotic cells contain a nucleus (where the DNA lives, and surrounded by a membrane) and various other special compartments surrounded by membranes, called organelles. For example, notice in this image the mitochondria, lysosomes, and peroxisomes.

Figure 3.12: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/592

The Plasma Membrane and Cytosol

Both eukaryotic and prokaryotic cells have walls around them that separate them from other cells and make sure the parts of the cell do not just float away. This wall is called a plasma membrane. The **plasma membrane** is made of a double layer of lipids, known as phospholipids. The function of the plasma membrane, also known as the cell membrane, is to control what goes in and out of the cell.

Some molecules can go through the cell membrane and enter and leave the cell, but some cannot. "Permeable" means that anything can cross a barrier. An open door is completely permeable to anything that wants to enter or exit through the door. The plasma membrane is **semipermeable,** meaning that some things can enter the cell and some things cannot.

The inside of eukaryotic and prokaryotic cells also both contain a jelly-like substance called **cytosol**. Cytosol is composed of water and other molecules, including enzymes that speed up the cell's chemical reactions. Everything in the cell - the nucleus and the organelles - sit in the cytosol, like fruit in a Jell-o mold. The term **cytoplasm** refers to the cytosol and all of the organelles, but not the nucleus.

Table 3.2: **Some Eukaryotic Organelles**

Organelle	Function
Ribosomes	Involved in making proteins
Golgi apparatus	Packages proteins and some polysaccharides
Mitochondria	Where ATP is made
Smooth Endoplasmic Reticulum	Makes lipids
Chloroplast	Makes sugar (photosynthesis)
Lysosomes	Digests macromolecules

The Nucleus

The nucleus is only found in eukaryotic cells. It is a membrane-bound structure that contains most of the genetic material of the cell (**Figure** 3.13). The nucleus contains important information that helps the cell create important molecules for life. The **nuclear envelope**, a double membrane that surrounds the nucleus, controls which molecules go in and out of the nucleus.

Inside of the nucleus, you will find the chromosomes. **Chromosomes** are strands of DNA wrapped around proteins. They contain genes, or small units of genetic material that create proteins.

Organelles in the Cytoplasm: The Cell Factory

A cell is like a factory. Just as a factory is made up of many people and machines, a cell has many different parts, each with a special role. The different parts of the cell are called **organelles**, which means "small organs." All organelles are found in eukaryotic cells, but most are NOT found in prokaryotic cells. Pay attention to which ones are included in prokaryotic cells.

Below are the main organelles found in cells:

1. The nucleus of a cell is like a safe containing the factory's trade secrets, including information about how to build thousands of proteins.
2. The **mitochondria** are powerhouses that create ATP (adenosine triphosphate), which provides the energy needed to power chemical reactions. Plant cells have special organelles called **chloroplasts** that capture energy from the sun and store it in the bonds of sugar molecules, using a process called

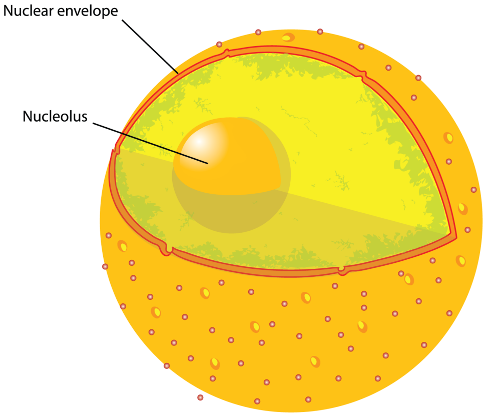


Figure 3.13: In eukaryotic cells, the DNA is kept in a nucleus. The nucleus is surrounded by a double plasma membrane called the nuclear envelope. Within the nucleus is the (smaller yellow ball).

photosynthesis (**Figure** 3.14). (The cells of animals and fungi do not photosynthesize and do not have chloroplasts.)

3. The **vacuoles** are like storage centers. Plant cells have larger ones than animal cells because they need to store water and other nutrients.
4. The **lysosomes** are like the recycling trucks that carry waste away from the factory. Inside lysosomes are enzymes that break down old molecules into parts that can be recycled into new ones.
5. Eukaryotic cells also contain a skeleton-like structure called the **cytoskeleton**. Like our bony skeleton, a cell's cytoskeleton gives the cell its shape and helps the cell to move. What part of a factory would act like a cytoskeleton?
6. In both eukaryotes and prokaryotes, **ribosomes** are where proteins are made. Ribosomes are like the machines in the factory that produce the factory's main product. Proteins are the main product of the cell.
7. Some ribosomes can be found on folded membranes called the endoplasmic reticulum (ER). If the ER is covered with ribosomes, it looks bumpy and is called **rough endoplasmic reticulum**. If the ER does not contain ribosomes, it is smooth and called the **smooth endoplasmic reticulum**. Proteins are made on the rough ER. Lipids are made on the smooth ER.
8. The **Golgi apparatus**, works like a mail room. The Golgi apparatus receives the proteins from the rough ER, puts ”shipping addresses” on the proteins, packages them up in vesicles, and then sends them to the right place in the cell.

You can watch an interactive animation of plant and animal cells at the following link: `http://www.cellsalive.com/cells/cell_model.htm.`

Differences between Plant and Animal Cells

Even though plants and animals are both eukaryotes, plant cells differ in some ways from animal cells. First, plant cells have a large central vacuole that holds a mixture of water, nutrients, and wastes. A plant cell's vacuole can make up 90% of the cell's volume. In animal cells, vacuoles are much smaller.

Second, plant cells have a cell wall, while animal cells do not. A **cell wall** gives the plant cell strength and protection.

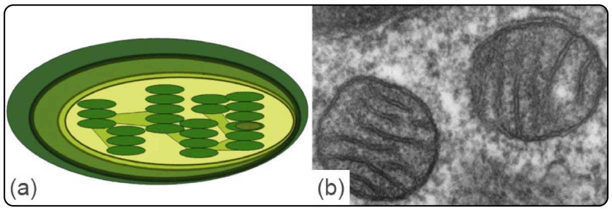


Figure 3.14: Diagram of chloroplast (a) and electron microscope image of two mitochondria (b). Chloroplasts and mitochondria provide energy to cells. If the bar at the bottom of the electron micrograph image is 200 nanometers, what is the diameter of one of the mitochondria?

A third difference between plant and animal cells is that plants have several kinds of organelles called **plastids**. There are several kinds of plastids, including chloroplasts, needed for photosynthesis; **leucoplasts**, which store starch and oil; and brightly colored **chromoplasts**, which give some flowers and fruits their yellow, orange, or red color. You will learn more about chloroplasts and photosynthesis in the chapter titled *Cell Functions*. Under a microscope one can see plant cells more clearly (**Figure** 3.15 and **Figure** 3.16).

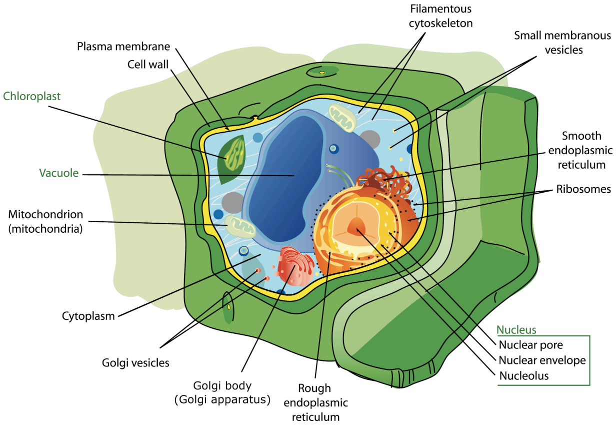


Figure 3.15: A plant cell has several features that make it different from an animal cell, including a cell wall, huge vacuoles, and several kinds of plastids, including chloroplasts (which photosynthesize).

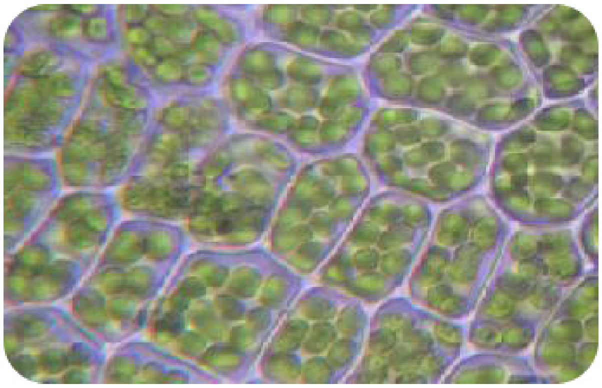


Figure 3.16: In this photo of plant cells taken with a light microscope, you can see a cell wall (purple) around each cell and green chloroplasts.

Lesson Summary

- Prokaryotic cells lack a nucleus; eukaryotic cells have a nucleus.
- Each component of a cell has a specific function.
- Plant cells are different from animal cells. For example, plant cells contain plastids, cell walls, and large vacuoles.

Review Questions

Recall

1. What are the two basic types of cells?
2. What are organelles?
3. Discuss the main differences between prokaryotic cells and eukaryotic cells.

Apply Concepts

4. What is the plasma membrane and what is its role?
5. Why is the mitochondria known as the powerhouse of the cell?

Think Critically

6. Why does photosynthesis not occur in animal cells?

Further Reading / Supplemental Links

- Baeuerle, Patrick A. and Landa, Norbert. *The Cell Works: Microexplorers.* Barron's; 1997, Hauppauge, New York.
- Sneddon, Robert. *The World of the Cell: Life on a Small Scale.* Heinemann Library; 2003, Chicago.
- Wallace, Holly. *Cells and Systems.* Heinemann Library; 2001, Chicago.

Points to Consider

- Think about what molecules would need to be transported into cells.
- Discuss why you think it would be important for some molecules to be kept out of a cell.

Image Sources

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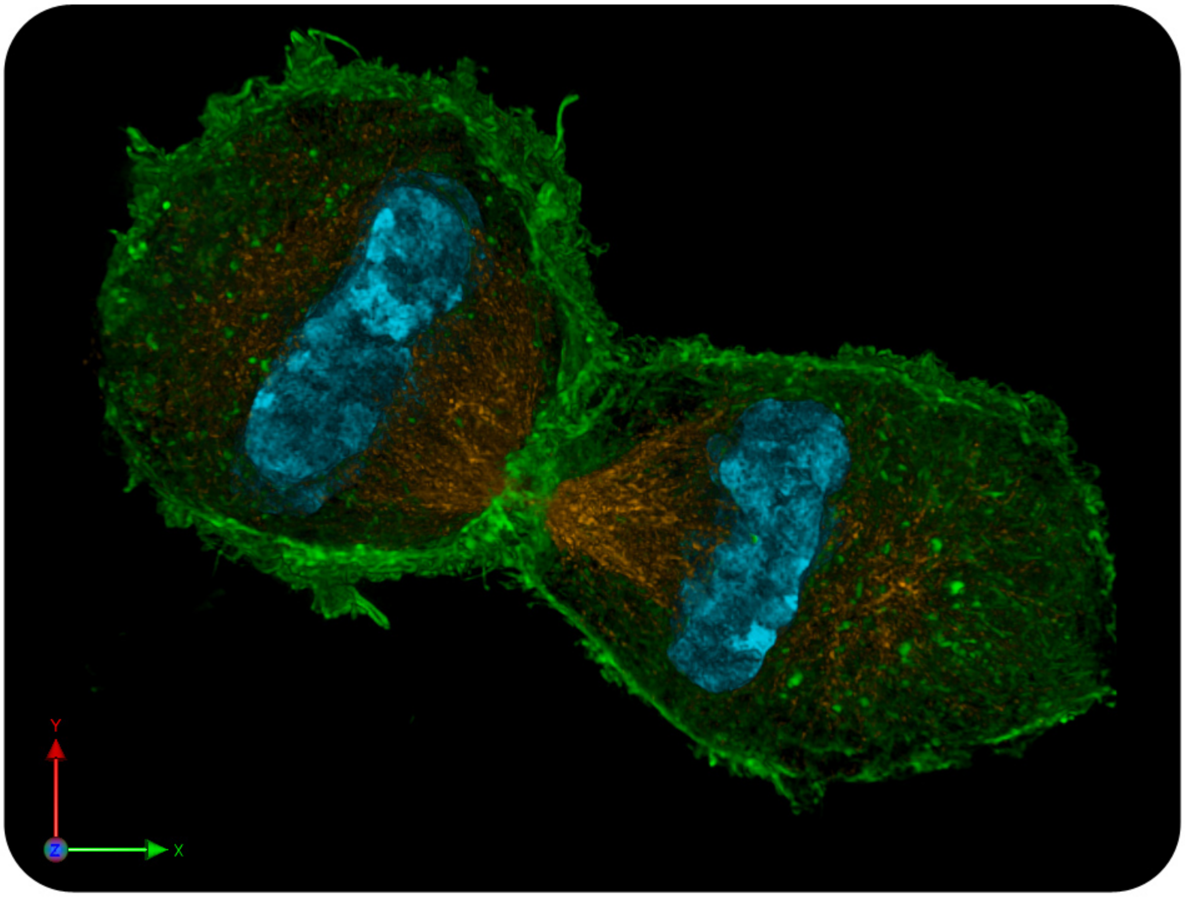
Chapter 4

MS Cell Division, Reproduction, and DNA



What has to happen for a cell to divide? Plenty. The above image shows the mitotic spindle in a sand dollar embryo. The mitotic spindle separates DNA in cells that are dividing. But that is just one step in the process. Why do you think cells need to divide? Do all cells divide the same way? How do cells help us reproduce? What would happen to living things if their cells failed to divide? What happens if cells divide uncontrollably? Think about these questions as you begin to understand why and how cells divide and how cell division helps the reproduction of all living things.

4.1 Cell Division

Lesson Objectives

- Explain why cells need to divide.
- List the stages of the cell cycle and explain what happens at each stage.
- List the stages of mitosis and explain what happens at each stage.

Check Your Understanding

- What is the cell theory?
- In what part of your cells is the genetic information located?

Vocabulary

- anaphase
- cancer
- cell cycle
- chromosome
- cytokinesis
- daughter cell
- interphase
- metaphase
- mitosis
- parent cell
- prophase
- sister chromatids
- spindle
- telophase

Why Cells Divide

Imagine the first stages of life. In humans, a sperm fertilizes an egg, forming the first cell. But humans are made up of trillions of cells, so where do the new cells come from? Remember that according to cell theory, all cells must come from existing cells. From that one cell, an entire baby will develop.

How does a new life go from one cell to so many? The cell divides in half, creating two cells. Then those two cells divide, for a total of four cells. The new cells continue to divide and divide. One cell becomes two, then four, then eight, and so on (**Figure** 4.1).

Besides the development of a baby, there are many other reasons that cell division is necessary for life:

1. To grow and develop, you must form new cells. Imagine how often your cells must divide during a growth spurt. Growing just an inch requires countless cell divisions.
2. Cell division is also necessary to repair damaged cells. Imagine you cut your finger. After the scab forms, it will eventually disappear and new skin cells will grow to repair the wound. Where do these cells come from? Some of your existing skin cells divide and produce new cells.
3. Your cells can also simply wear out. Over time you must replace old and worn-out cells. Cell division is essential to this process.

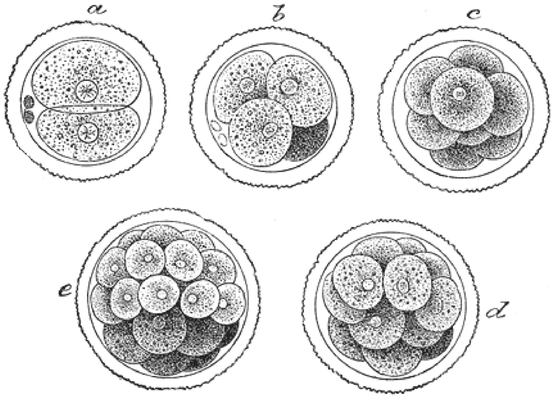


Figure 4.1: Cells divide repeatedly to produce an embryo. Previously the one-celled zygote (the first cell of a new organism) divided to make two cells (a). Each of the two cells divides to yield four cells (b), then the four cells divide to make eight cells (c), and so on. Through cell division, an entire embryo forms from one initial cell.

The Cell Cycle

The process of cell division in eukaryotic cells is carefully controlled. The **cell cycle** is the lifecycle of a cell, with cell division at the end of the cycle. Like a human lifecycle that is made up of different phases, like childhood, adolescence, and adulthood, there are a series of steps that lead to cell division (**Figure** 4.2).

These steps can be divided into two main components, interphase and mitosis.

1. Interphase: The stage when the cell mostly performs its "everyday" functions. For example, it is when a kidney cell does what a kidney cell is supposed to do.
2. Mitosis: The stage when the cell prepares to become two cells.

Most of the cell cycle consists of **interphase,** the time between cell divisions. Interphase can be divided into three stages:

1. The first growth phase (G1): During the G1 stage, the cell doubles in size and doubles the number of organelles.
2. The synthesis phase (S): The DNA is replicated during this phase. In other words, an identical copy of all the cell's DNA is made. This ensures that each new cell has a set of genetic material identical to that of the parental cell. DNA replication will be further discussed in lesson 5.3.
3. The second growth phase (G2): Proteins are synthesized that will help the cell divide. At the end of interphase, the cell is ready to enter mitosis.

During **mitosis**, the nucleus divides. Mitosis is followed by **cytokinesis**, when the cytoplasm divides, resulting in two cells. After cytokinesis, cell division is complete. Scientists say that one **parent cell**, or the dividing cell, forms two genetically identical **daughter cells,** or the cells that divide from the parent cell. The term "genetically identical" means that each cell has an identical set of DNA, and this DNA is also identical to that of the parent cell. If the cell cycle is not carefully controlled, it can cause a disease called **cancer**, which causes cell division to happen too fast. A tumor can result from this kind of growth.

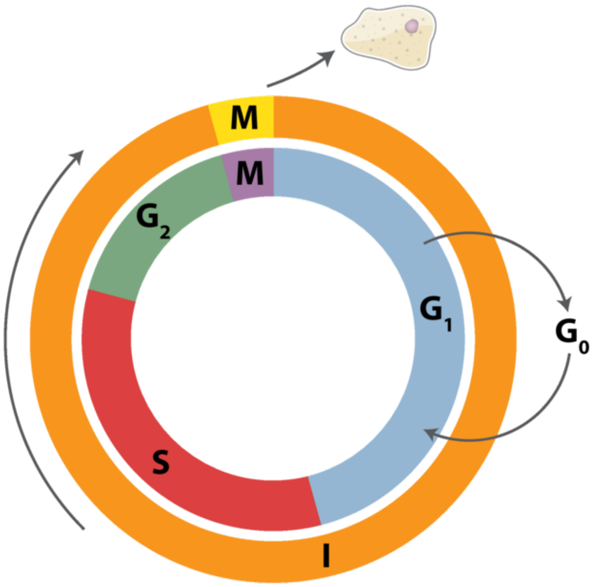


Figure 4.2: The cell cycle is the repeated process of growth and division. Notice that most of the cell cycle is spent in interphase (G1, S, and G2) (I). G0 is a resting state of the cell cycle.

Cancer is discussed in the video at `http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/11/RZhL7LDPk8w`. (12:36).

Figure 4.3: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/126

Two animations of the cell cycle are available at the following links. See if you can explain what is happening in these animations.

- `http://www.wisc-online.com/objects/index_tj.asp?objID=AP13604`
- `http://www.cellsalive.com/cell_cycle.htm`

Mitosis and Chromosomes

The genetic information of the cell, or DNA, is stored in the nucleus. During mitosis, two nuclei (plural for nucleus) must form, so that one nucleus can be in each of the new cells. The DNA inside of the nucleus is also copied. The copied DNA needs to be moved into the nucleus, so each cell can have a correct set of genetic instructions.

To begin mitosis, the DNA in the nucleus wraps around proteins to form **chromosomes**. Each organism has a unique number of chromosomes. In human cells, our DNA is divided up into 23 pairs of chromosomes.

After the DNA is replicated during the S stage of interphase, each chromosome has two identical molecules of DNA, called **sister chromatids**, forming the ”X” shaped molecule depicted in **Figure** 4.4.

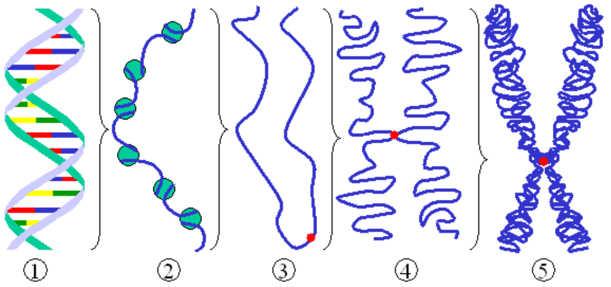


Figure 4.4: The DNA double helix wraps around proteins (2) and tightly coils a number of times to form a chromosome (5). This figure shows the complexity of the coiling process. The red dot shows the location of the centromere, where the microtubules attach during mitosis and meiosis.

The Four Phases of Mitosis

During mitosis, the two sister chromatids must be split apart. Each resulting chromosome is made of *1/2* of the ”X”. Through this process, each daughter cell receives one copy of each chromosome. Mitosis is divided into four phases (**Figure** 4.5):

1. **Prophase**: The chromosomes ”condense,” or become so tightly wound that you can see them under a microscope. The wall around the nucleus, called the nuclear envelope, disappears. **Spindles** also form and attach to chromosomes to help them move.
2. **Metaphase**: The chromosomes line up in the center of the cell. The chromosomes line up in a row, one on top of the next.
3. **Anaphase**: The two sister chromatids of each chromosome separate, resulting in two sets of identical chromosomes.
4. **Telophase**: The spindle dissolves and nuclear envelopes form around the chromosomes in both cells.

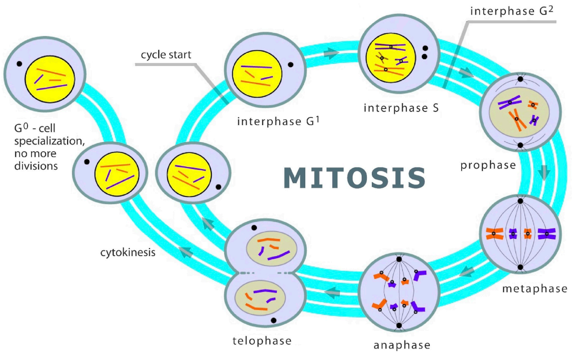


Figure 4.5: An overview of the cell cycle and mitosis: during prophase the chromosomes condense, during metaphase the chromosomes line up, during anaphase the sister chromatids are pulled to opposite sides of the cell, and during telophase the nuclear envelope forms.

Each new nucleus contains the exact same number and type of chromosomes as the original cell. The cell is now ready for cytokinesis, which literally means ”cell movement.” The cells separate, producing two genetically identical cells, each with its own nucleus. **Figure** 4.7 is a representation of dividing plant cells.

The phases of mitosis are discussed in the video: `http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/8/LLKX_4DHE3I` (20:42).

Figure 4.6: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/128

Additional animations of mitosis can be viewed at the following links:

- `http://www.cellsalive.com/mitosis.htm`
- `http://www.youtube.com/watch?v=7hQ5xXJSmK4&#38;feature=related`

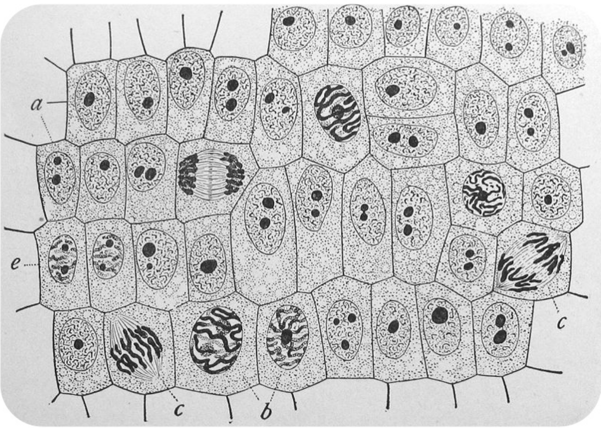


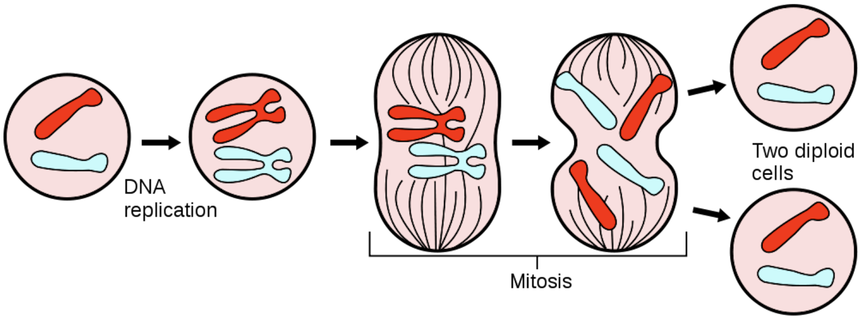
Figure 4.7: This is a representation of dividing plant cells. Cell division in plant cells differs slightly from animal cells as a cell wall must form. Note that most of the cells are in interphase. Can you find examples of the different stages of mitosis?

Mitosis in Real Time can be viewed at `http://www.youtube.com/watch?v=m73i1Zk8EA0&#38;feature=related` (0:19).

Lesson Summary

- Cells divide for growth, development, reproduction and replacement of injured or worn-out cells.
- The cell cycle is a series of controlled steps by which a cell divides.
- During mitosis, the newly duplicated chromosomes are divided into two daughter nuclei.
- This summary diagram depicts one cell dividing into two genetically identical cells. Mitosis occurs after DNA replication. A diploid cell has two sets of chromosomes, as is shown here.

Figure 4.8: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/598



Review Questions

Recall

1. In what phase of mitosis are chromosomes moving toward opposite sides of the cell?
2. In what phase of mitosis do the duplicated chromosomes condense?
3. What step of the cell cycle is the longest?
4. What is the term for the division of the cytoplasm?
5. What happens during the S stage of interphase?

Apply Concepts

6. Interphase used to be considered the “resting” stage of the cell cycle. Why is this not correct?
7. What are some reasons that cells divide?
8. During what stage of the cell cycle does the cell double in size?
9. Why must cell division be tightly regulated?

Critical Thinking

10. What would happen if the cells in your liver stopped going through the process of mitosis?
11. What do you think might happen if mitosis could NOT stop happening to the cells in your brain?

Further Reading / Supplemental Links

- `http://en.wikipedia.org/wiki/Mitosis`
- `http://www.biology.arizona.edu/Cell_bio/tutorials/cell_cycle/cells3.html`
- `http://biology.clc.uc.edu/courses/bio104/mitosis.htm`
- `http://en.wikipedia.org/wiki/Cell_cycle`

Points to Consider

- How might a cell without a nucleus divide?
- How are new cells made that include the DNA of two parents?

4.2 Reproduction

Lesson Objectives

- Name the types of asexual reproduction.
- Explain the advantage of sexual reproduction.
- List the stages of meiosis and explain what happens in each stage.

Check Your Understanding

- Can something that does not reproduce still be considered living?
- What stores the genetic information that is passed on to offspring?
- How many chromosomes are in the human nucleus?

Vocabulary

- allele
- asexual reproduction
- binary fission
- crossing-over
- cross-pollination
- diploid
- external fertilization
- gamete
- gonad
- haploid
- internal fertilization
- meiosis
- ovaries
- parthenogenesis
- sexual reproduction
- testes
- zygote

What is reproduction?

What does reproduction mean? Can an organism be considered alive if it cannot make the next generation? Since individuals cannot live forever, they must reproduce for the species to survive. Reproduction is the ability to make the next generation.

Two methods of reproduction are:

1. **Asexual reproduction**, or the process of forming a new individual from a single parent.
2. **Sexual reproduction**, or the process of forming a new individual from two parents.

There are advantages and disadvantages to each method, but the result is always the same: a new life begins.

Asexual Reproduction

For humans to reproduce, DNA must be passed from the mother and father to the child. Humans cannot reproduce with just one parent, but it is possible in other organisms, like bacteria, some insects and some fish. These organisms can reproduce asexually, meaning that the offspring (children) have a single parent and share the exact same genetic material as the parent. This is very different from humans.

The advantage of asexual reproduction is that it can be very quick and does not require the meeting of a male and female organism. The disadvantage of asexual reproduction is that organisms cannot mix beneficial traits from both parents. An organism that is born through asexual reproduction only has the DNA from the one parent, and it is the exact copy of that parent. This can cause problems for the individual. For example, if the parent organism has a gene that causes cancer, the offspring will also have the gene that causes cancer. Organisms produced sexually may or may not inherit the cancerous gene because there are two parents mixing up their genes.

Types of organisms that reproduce asexually include:

1. Prokaryotic organisms, like bacteria. Bacteria reproduce through **binary fission,** where they grow and divide in half (**Figure** 4.9). First, their chromosome replicates (bacteria only have one chromosome) and the cell enlarges. After cell division, the two new cells each have one identical chromosome (mitosis is not necessary because bacteria do not have nuclei). Then, new membranes form to separate the two cells. This simple process allows bacteria to reproduce very rapidly.
2. Flatworms, an animal species. Flatworms divide in two, then each half regenerates into a new flatworm identical to the original.
3. Different types of insects, fish, and lizards. These organisms can reproduce asexually through a process called parthenogenesis (**Figure** 4.10). **Parthenogenesis** happens when an unfertilized egg cell grows into a new organism. The resulting organism has half the amount of genetic material of the parent. Parthenogenesis is common in honeybees. In a hive, the sexually produced eggs become workers, while the asexually produced eggs become drones.

Sexual Reproduction

During sexual reproduction, two parents are involved. Most animals are dioecious, meaning there is a separate male and female sex, with the male producing sperm and the female producing eggs. When a sperm and egg meet, a **zygote,** the first cell of a new organism, is formed (**Figure** 4.11). The zygote will divide and grow into the embryo.

Let's explore how animals, plants, and fungi reproduce sexually:

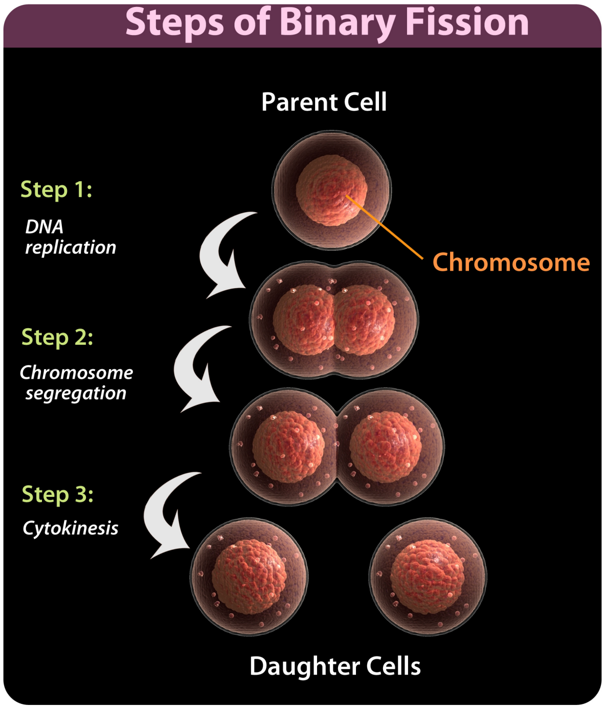


Figure 4.9: Bacteria reproduce by binary fission. Shown is one bacterium reproducing and becoming two bacteria.

Figure 4.10: This Komodo dragon was born by parthenogenesis.

Figure 4.11: During sexual reproduction, a sperm fertilizes an egg.

- Animals often have **gonads,** organs that produce eggs or sperm. The male gonads are the **testes,** which produce the sperm, and the female gonads are the **ovaries,** which produce the eggs. Sperm and egg, the two sex cells, are known as **gametes**, and can combine two different ways:

1. Fish and other aquatic animals release their gametes in the water, which is called **external fertilization.** These gametes will combine by chance. (**Figure** 4.12).
2. Animals that live on land reproduce by **internal fertilization**. Typically males have a penis that deposits sperm into the vagina of the female. Birds do not have penises, but they do have a chamber called the cloaca that they place close to another bird's cloaca to deposit sperm.

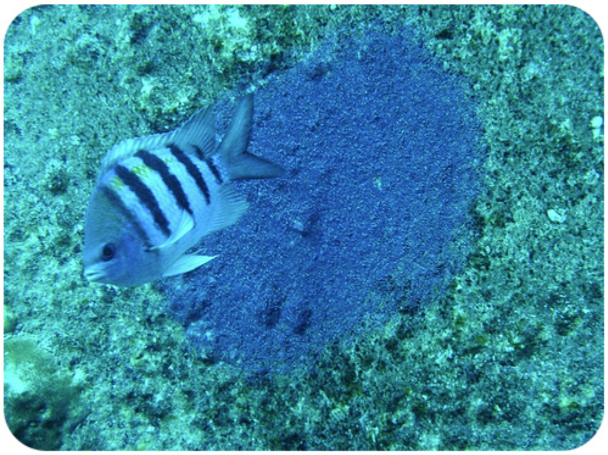


Figure 4.12: This fish guards her eggs, which will be fertilized externally.

- Plants can also reproduce sexually, but their reproductive organs are different from animals' gonads. Plants that have flowers have their reproductive parts in the flower. The sperm is contained in the pollen, while the egg is contained in the ovary, deep within the flower. The sperm can reach the egg two different ways:

1. In self-pollination, the egg is fertilized by the pollen of the same flower.
2. In **cross-pollination**, sperm from the pollen of one flower fertilizes the egg of another flower. Like other types of sexual reproduction, cross-pollination allows new combinations of traits. Cross-pollination occurs when pollen is carried by the wind to another flower. It can also occur when animal pollinators, like honeybees, or butterflies (**Figure** 4.13) carry the pollen from flower to flower.

- Fungi can also reproduce sexually, but instead of female and male sexes, they have (+) and (-) strains. When the filaments of a (+) and (-) fungi meet, the zygote is formed. Just like in plants and animals, each zygote receives DNA from two parent strains.

Figure 4.13: Butterflies receive nectar when they deposit pollen into flowers, resulting in cross-pollination.

Meiosis and Gametes

Meiosis is a process of cell division that produces sex cells, or gametes. Gametes are reproductive cells, such as sperm and egg. As gametes are produced, the number of chromosomes must be reduced by half. Why? The zygote must contain information from the mother and from the father, so the gametes must contain half of the chromosomes found in normal body cells.

In humans, our cells have 23 pairs of chromosomes, and each chromosome within a pair is called a **homologous chromosome.** For each of the 23 chromosome pairs, you received one chromosome from your father and one chromosome from your mother. The homologous chromosomes are separated when gametes are formed. Therefore, gametes have only 23 chromosomes, not 23 pairs.

Alleles are alternate forms of genes found on chromosomes. Since the separation of chromosomes into gametes is random, it results in different combinations of chromosomes (and alleles) in each gamete. With 23 pairs of chromosomes, there is a possibility of over 8 million different combinations of chromosomes in a gamete.

Haploid vs. Diploid

A cell with two sets of chromosomes is **diploid**, referred to as $2n$, where n is the number of sets of chromosomes. Most of the cells in a human body are diploid. A cell with one set of chromosomes, such as a gamete, is **haploid,** referred to as n. Sex cells are haploid. When a haploid sperm (n) and a haploid egg (n) combine, a diploid zygote will be formed ($2n$). In short, when a diploid zygote is formed, half of the DNA comes from each parent.

Meiosis

Before meiosis begins, DNA replication occurs, so each chromosome contains two sister chromatids that are identical to the original chromosome.

Meiosis is divided into two divisions: Meiosis I and Meiosis II. Each division is similar to mitosis and can be divided into the same phases: prophase, metaphase, anaphase, and telophase. Between the two divisions, DNA replication does not occur. Through this process, one diploid cell will divide into four haploid cells.

The phases of meiosis are discussed at `http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/9/ijLc52LmFQg` (27:23).

Figure 4.14: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/130

Meiosis I

During meiosis I, the pairs of homologous chromosomes are separated from each other.

1. Prophase I: The homologous chromosomes line up together. During this time, a process that only happens in meiosis can occur. This process is called **crossing-over** (**Figure** 4.15), which is the exchange of DNA between homologous chromosomes. Crossing-over increases the new combinations of alleles in the gametes. Without crossing-over, the offspring would always inherit all of the many alleles on one of the homologous chromosomes. Also during prophase I, the spindle forms, the chromosomes condense as they coil up tightly, and the nuclear envelope disappears.
2. Metaphase I: The homologous chromosomes line up in pairs in the middle of the cell. Chromosomes from the mother or from the father can each attach to either side of the spindle. Their attachment is random, so all of the chromosomes from the mother or father do not end up in the same gamete. The gamete will contain some chromosomes from the mother and some chromosomes from the father.
3. Anaphase I: The homologous chromosomes separate.
4. Telophase I: The spindle fibers dissolves, but a new nuclear envelope does not need to form. This is because the nucleus will divide again. No DNA replication happens between meiosis I and meiosis II because the chromosomes are already duplicated.

Meiosis II

During meiosis II, the sister chromatids are separated and the gametes are generated.

The steps are outlined below:

1. Prophase II: The chromosomes condense.

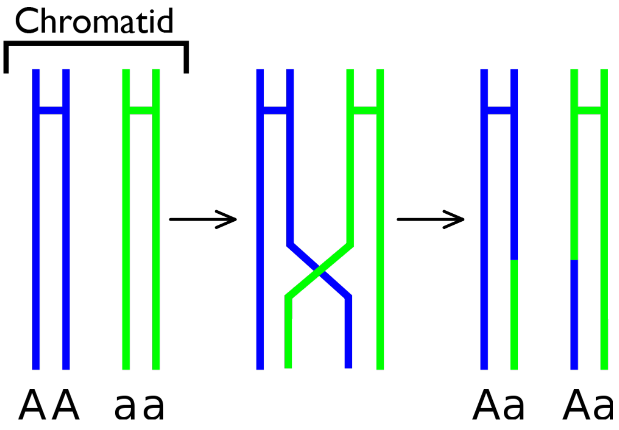


Figure 4.15: During crossing-over, segments of DNA are exchanged between sister chromatids. Notice how this can result in an allele (A) on one sister chromatid being moved onto the other sister chromatid.

2. Metaphase II: The chromosomes line up one on top of the next along the middle of the cell.
3. Anaphase II: The sister chromatids separate.
4. Telophase II: Nuclear envelopes form around the chromosomes in all four cells.

After cytokinesis, each cell has divided again. Therefore, meiosis results in four daughter cells with half the DNA of the parent cell (**Figure** 4.16). In human cells, the parent cell has 46 chromosomes, so the cells produced by meiosis have 23 chromosomes. These cells will become gametes.

Mitosis vs. Meiosis: A Comparison

Mitosis, meiosis and sexual reproduction are discussed at `http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/7/kaSIjIzAtYA` (18:23).

Figure 4.18 is a comparison between binary fission, mitosis, and meiosis. Mitosis and meiosis are also compared in **Table** 4.1.

Animations of meiosis can be found at the following sites:

- `http://www.cellsalive.com/meiosis.htm`
- `http://www.youtube.com/watch?v=MqaJqLL49a0&#38;NR=1`
- `http://www.youtube.com/watch?v=uh7c8YbYGqo&#38;feature=related`

Table 4.1: **Mitosis vs. Meiosis: A Comparison**

	Mitosis	**Meiosis**
Purpose:	To produce new cells	To produce gametes
Number of cells produced:	2	4
Rounds of Cell Division:	1	2
Haploid or Diploid:	Diploid	Haploid
Daughter cells identical to parent cells?	Yes	No
Daughter cells identical to each other?	Yes	No

Lesson Summary

- Organisms can reproduce sexually or asexually.
- The gametes in sexual reproduction must have half the DNA of the parent.

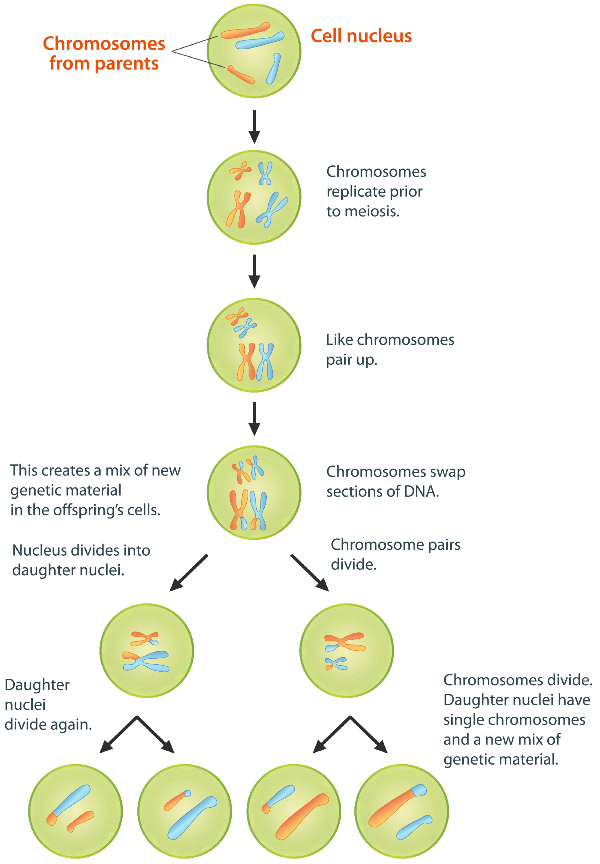

Chromosomes from parents
Cell nucleus
Chromosomes replicate prior to meiosis.
Like chromosomes pair up.
This creates a mix of new genetic material in the offspring's cells.
Chromosomes swap sections of DNA.
Nucleus divides into daughter nuclei.
Chromosome pairs divide.
Daughter nuclei divide again.
Chromosomes divide. Daughter nuclei have single chromosomes and a new mix of genetic material.

Figure 4.16: An overview of meiosis.

Video

Figure 4.17: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/129

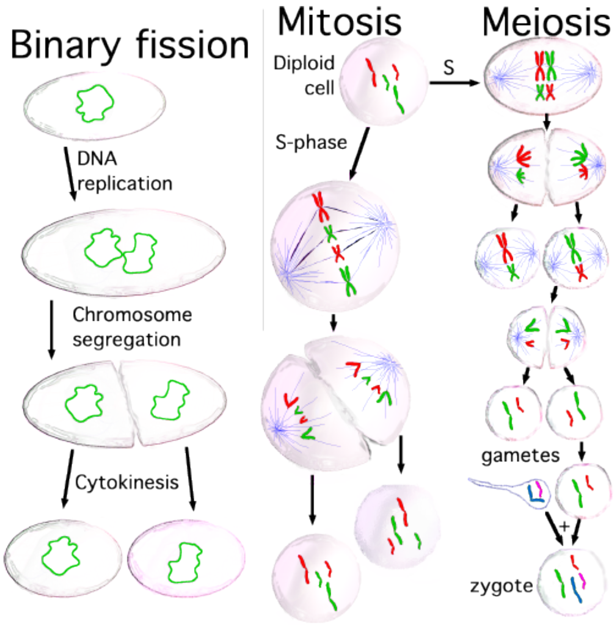


Figure 4.18: A comparison between binary fission, mitosis, and meiosis.

4. In what phase of meiosis do homologous chromosomes pair up?

Apply Concepts

5. Explain how organisms reproduce asexually.
6. Explain how birds fertilize their eggs.
7. How do most plants reproduce sexually?
8. Compare and contrast the process of mitosis and the process of meiosis.

Critical Thinking

9. How would sexual reproduction in a lizard be different than in a fish?
10. What is the advantage of sexual reproduction over asexual reproduction?
11. If an organism has 12 chromosomes in its cells, how many chromosomes will be in its gametes?

Further Reading / Supplemental Links

- `http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookmeiosis.html`
- `http://www.biology.arizona.edu/Cell_BIO/tutorials/meiosis/page3.html`
- `http://en.wikipedia.org/`

Points to Consider

- What must be replicated prior to mitosis?
- How do you think DNA might be replicated?

- What might happen if there is a mistake during DNA replication?

4.3 DNA, RNA, and Protein Synthesis

Lesson Objectives

- Explain the chemical composition of DNA.
- Explain how DNA synthesis works.
- Explain how proteins are coded for and synthesized.
- Describe the three types of RNA and the functions of each.

Check Your Understanding

- What is the purpose of DNA?
- When is DNA replicated?

Vocabulary

- amino acid
- DNA
- DNA replication
- double helix
- gene
- mutagen
- mutation
- nucleotide
- RNA
- semiconservative replication
- transcription
- translation

What is DNA?

DNA, is the material that makes up our chromosomes and stores our genetic information. When you build a house, you need a blueprint, a set of instructions that tells you how to build. The DNA is like the blueprint for living organisms. The genetic information is a set of instructions that tell your cells what to do.

DNA is an abbreviation for deoxyribonucleic acid. As you may recall, nucleic acids are a type of macromolecule that store information. The *deoxyribo* part of the name refers to the name of the sugar that is contained in DNA, deoxyribose. DNA may provide the instructions to make up all living things, but it is actually a very simple molecule. DNA is made of a long chain of nucleotides.

Nucleotides are composed of 3 main parts:

1. Phosphate group
2. 5-carbon sugar
3. Nitrogen-containing base

The only difference between each nucleotide is the identity of the base. There are only four possible bases that make up each DNA nucleotide: adenine (A), guanine (G), thymine (T), and cytosine (C).

The various sequences of these four bases make up the genetic code of your cells. It may seem strange that there are only four letters in the “alphabet” of DNA. But since your chromosomes contain millions of nucleotides, there are many, many different combinations possible with those four letters.

But how do all these pieces fit together? James Watson and Francis Crick won the Nobel Prize in 1962 for piecing together the structure of DNA. Together with the work of Rosalind Franklin and Maurice Wilkins, they determined that DNA is made of two strands of nucleotides formed into a **double helix**, or a two-stranded spiral, with the sugar and phosphate groups on the outside, and the paired bases connecting the two strands on the inside of the helix (**Figure** 4.19 and **Figure** 4.20).

Base-Pairing

The bases in DNA do not pair randomly. When Erwin Chargaff looked closely at the bases in DNA, he noticed that the percentage of adenine (A) in the DNA always equaled the percentage of thymine (T), and the percentage of guanine (G) always equaled the percentage of cytosine (C). Watson and Crick’s model explained this result by suggesting that A always pairs with T and G always pairs with C in the DNA helix. Therefore A and T, and G and C, are ”complementary bases,” or bases that always pair together. For example, if one DNA strand reads ATGCCAGT, the other strand will be made up of the complementary bases: TACGGTCA.

The vocabulary of DNA, including chromosomes, chromatids, chromatin, transcription, translation, and replication, is discussed at `http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/6/s9HPNwXd9fk` (18:23).

DNA Replication

The base pairing rules are crucial for the process of replication. **DNA replication** occurs when DNA is copied to form an identical molecule of DNA. DNA replication happens before cell division. Below are the steps involved in DNA replication:

1. The DNA helix unwinds like a zipper, as the bonds between the base pairs are broken.
2. The two single strands of DNA then each serve as a template for a new stand to be created. Using DNA as a template means that the bases are placed in the right order because of the base pairing rules. If ATG is on the ”template strand,” then TAC will be on the new DNA strand.
3. The new set of nucleotides then join together to form a new strand of DNA. The process results in two DNA molecules, each with one old strand and one new strand of DNA.

This process is known as **semiconservative replication** because one strand is conserved (kept the same) in each new DNA molecule (**Figure** 4.22).

Protein Synthesis

The DNA sequence contains the instructions to make units called amino acids, which are assembled in a specific order to make proteins. In short, DNA contains the instructions to create proteins. Each strand of DNA has many separate sequences that code for a specific protein. Units of DNA that contain code for the creation of one protein are called **genes.** An overview of protein synthesis can be seen at this animation: `http://www.biostudio.com/demo_freeman_protein_synthesis.htm`

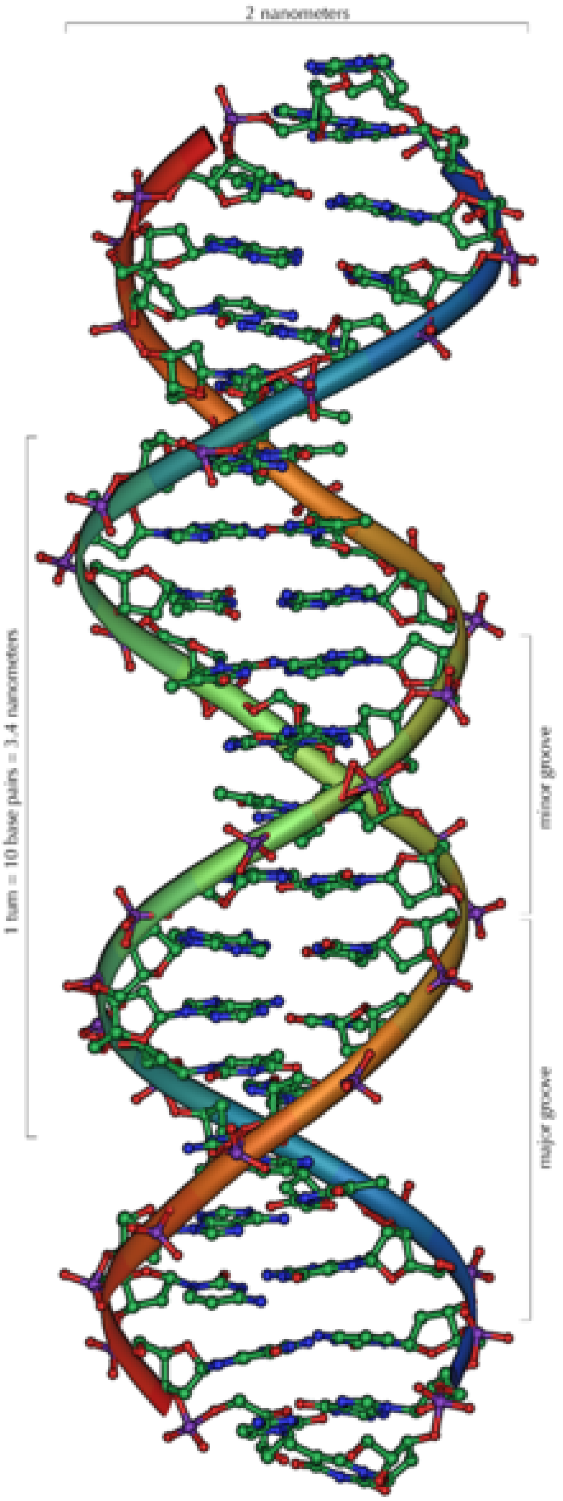


Figure 4.19: DNA's three-dimensional structure is a double helix. The hydrogen bonds between the bases at the center of the helix hold the helix together.

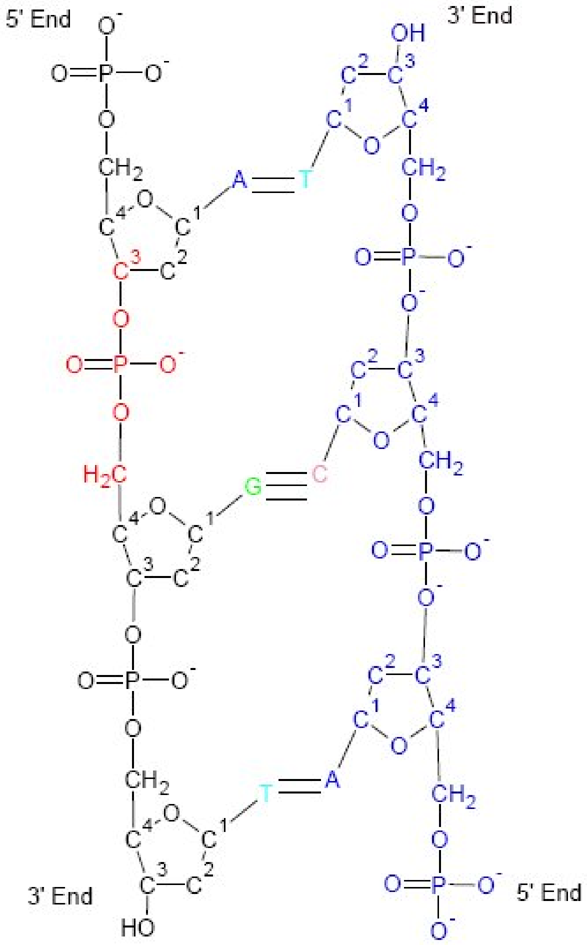


Figure 4.20: The chemical structure of DNA includes a chain of nucleotides consisting of a 5-carbon sugar, a phosphate group, and a nitrogen base. Notice how the sugar and phosphate form the backbone of DNA (one strand in blue), with the hydrogen bonds between the bases joining the two strands.

Figure 4.21: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/127

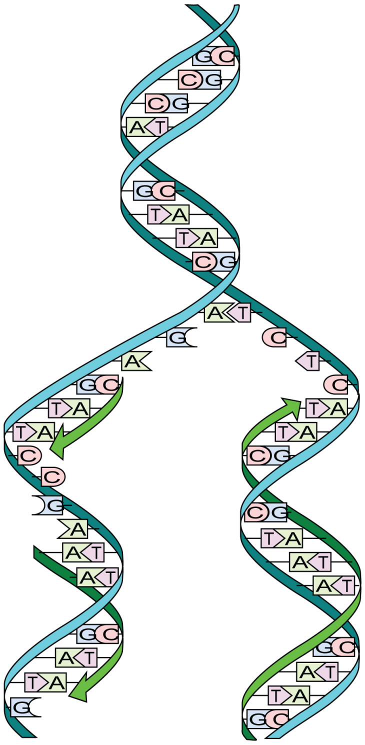


Figure 4.22: DNA replication occurs when the DNA strands "unzip", and the original strands of DNA serve as a template for new nucleotides to join and form a new strand.

Cells Can Turn Genes On or Off

There are about 22,000 genes in every human cell. Does every human cell have the same genes? Yes. Does every human cell use the same genes to make the same proteins? No. In a multicellular organism, such as us, cells have specific functions because they have different proteins. They have different proteins because different genes are expressed in different cell types.

Imagine that all of your genes are ”turned off.” Each cell type only ”turns on” (or expresses) the genes that have the code for the proteins it needs to use. So different cell types ”turn on” different genes, allowing different proteins to be made, giving different cell types different functions.

Three Types of RNA

DNA contains the instructions to create proteins, but it does not make proteins itself. DNA is located in the nucleus, while proteins are made on ribosomes in the cytoplasm. So DNA needs a messenger to bring its instructions to a ribosome located outside of the nucleus. DNA sends out a message, in the form of **RNA** (ribonucleic acid), describing how to make the protein.

There are three types of RNA directly involved in protein synthesis:

- Messenger RNA (mRNA) carries the instructions from the nucleus to the cytoplasm.
- The other two forms of RNA, ribosomal RNA (rRNA) and transfer RNA (tRNA) are involved in the process of ordering the amino acids to make the protein.

All three RNAs are nucleic acids, made of nucleotides, similar to DNA. The RNA nucleotide is different from the DNA nucleotide in the following ways:

- RNA contains a different kind of sugar, called ribose.
- In RNA, the base uracil (U) replaces the thymine (T) found in DNA.
- RNA is a single strand.

DNA Transcription

mRNA is created by using DNA as a template. The process of constructing an mRNA molecule from DNA is known as **transcription** (**Figure** 4.24 and **Figure** 4.25). The double helix of DNA unwinds and the nucleotides follow basically the same base pairing rules to form the correct sequence in the mRNA. This time, however, U pairs with each A in the DNA. In this manner, the genetic code is passed on to the mRNA.

Two multimedia links of protein synthesis are provided below.

- `http://www-class.unl.edu/biochem/gp2/m_biology/animation/gene/gene_a2.html`

Transcription and Translation can be viewed at `http://www.youtube.com/watch?v=41_Ne5mS2ls` (4:06).

RNA Translation

The mRNA is directly involved in the protein-making process. mRNA tells the ribosome (**Figure** 4.26) how to create a protein. The process of reading the mRNA code in the ribosome to make a protein is called

Figure 4.23: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/599

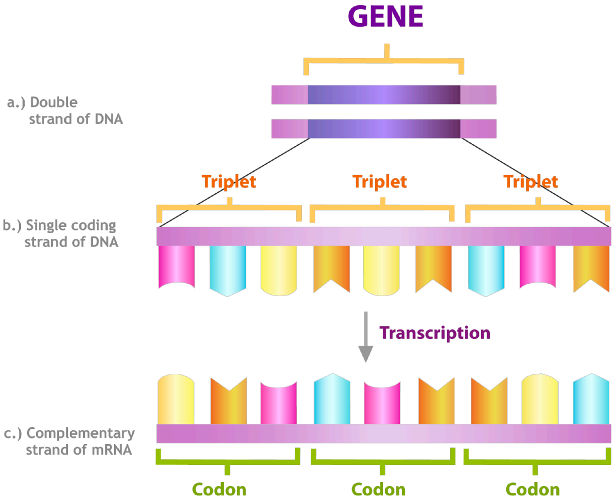


Figure 4.24: Each gene (a) contains triplets of bases (b) that are transcribed into RNA (c). Every triplet, or codon, encodes for a unique amino acid.

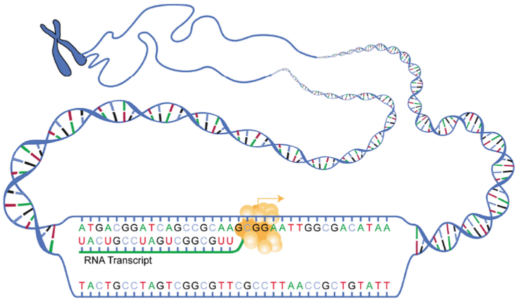

ATGACGGATCAGCCGCAAGCGGAATTGGCGACATAA
UACUGCCUAGUCGGCGUU
RNA Transcript
TACTGCCTAGTCGGCGTTCGCCTTAACCGCTGTATT

Figure 4.25: Base-pairing ensures the accuracy of transcription. Notice how the helix must unwind for transcription to take place.

translation (**Figure** 4.27). Sets of three bases, called codons, are read in the ribosome, the organelle responsible for making proteins.

The following are the steps involved in translation:

1. mRNA travels to the ribosome from the nucleus.
2. The base code in the mRNA determines the order of the amino acids in the protein. The genetic code in mRNA is read in "words" of three letters (triplets), called **codons.** There are 20 amino acids and different codons code for different ones. For example, GGU codes for the amino acid glycine, while GUC codes for valine.
3. tRNA reads the mRNA code and brings a specific amino acid to attach to the growing chain of amino acids. Each tRNA carries only one type of amino acid and only recognizes one specific codon.
4. tRNA is released from the amino acid.
5. Three codons, UGA, UAA, and UAG, indicate that the protein should stop adding amino acids. They are called "stop codons" and do not code for an amino acid. Once tRNA comes to a stop codon, the protein is set free from the ribosome.

The chart in **Figure** 4.28 is used to determine which amino acids correspond to which codons. An interactive activity for transcribing and translating a gene can be found at `http://learn.genetics.utah.edu/units/basics/transcribe/`.

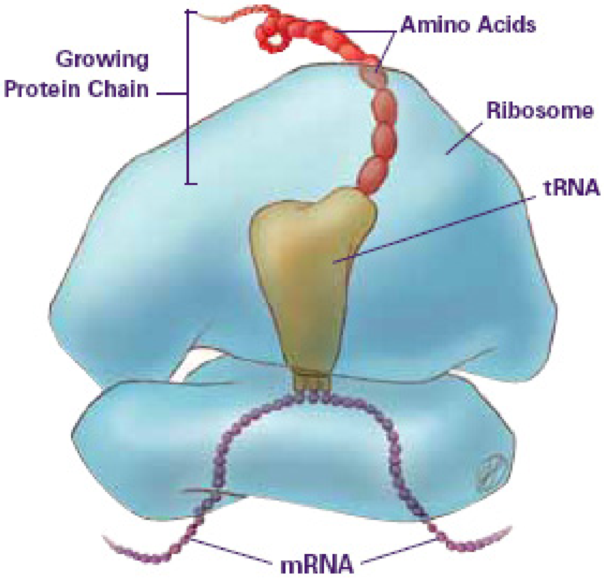


Figure 4.26: Ribosomes translate RNA into a protein with a specific amino acid sequence. The tRNA binds and brings to the ribosome the amino acid encoded by the mRNA. Ribosomes are made of rRNA and proteins.

Mutations

The process of DNA replication is not always 100% accurate, and sometimes the wrong base is inserted in the new strand of DNA. A permanent change in the sequence of DNA is known as a **mutation**. Small changes in the DNA sequence are usually point mutations, which is a change in a single nucleotide. A mutation may have no effect. Sometimes, a mutation can cause the protein to be made incorrectly, which can affect how well the protein works, or whether it works at all. Usually the loss of a protein function is detrimental to the organism.

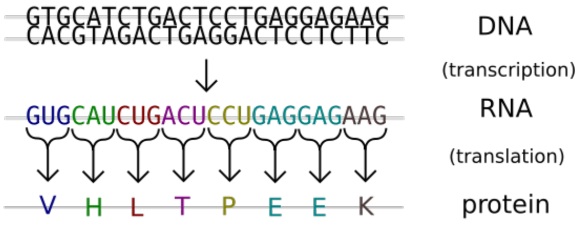


Figure 4.27: This summary of how genes are expressed shows that DNA is transcribed into RNA, which is translated in turn to protein.

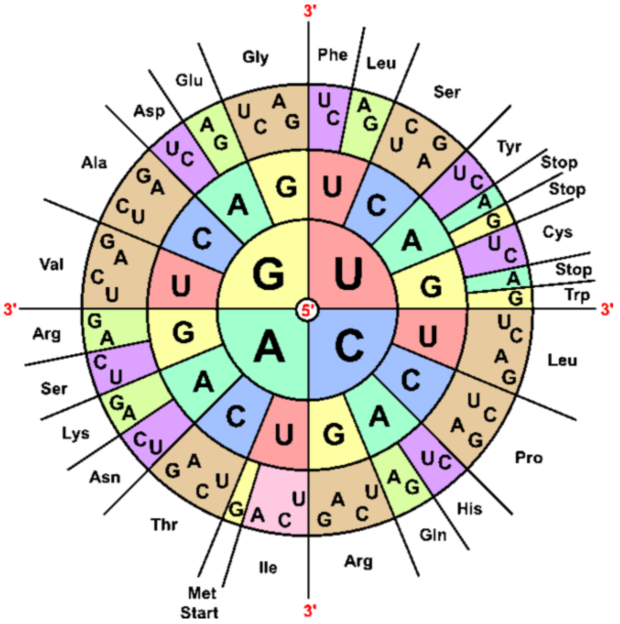


Figure 4.28: This chart shows the genetic code used by all organisms. For example, an RNA codon reading GUU would encode for a valine (Val) according to this chart. Start at the center for the first base of the three base codon, and work your way out. Notice for valine, the second base is a U and the third base of the codon may be either a G, C, A, or U. Similarly, glycine (Gly) is encoded by a GGG, GGA, GGC, and GGU.

However, in rare circumstances, the mutation can be beneficial. For example, suppose a mutation in an animal's DNA causes the loss of an enzyme that makes a dark pigment in the animal's skin. If the population of animals has moved to a light colored environment, the animals with the mutant gene would have a lighter skin color and be better camouflaged. So in this case, the mutation is beneficial.

Mutations may also occur in chromosomes. Possible types of mutations in chromosomes (**Figure** 4.29) include:

1. Deletion: When a segment of DNA is lost, so there is a missing segment in the chromosome.
2. Duplication: When a segment of DNA is repeated, creating a longer chromosome.
3. Inversion: When a segment of DNA is flipped and then reattached to the chromosome.
4. Insertion: When a segment of DNA from one chromosome is added to another, unrelated chromosome.
5. Translocation: When two segments from different chromosomes change positions.

If a single base is deleted (called a point mutation), there can be huge effects on the organism because this may cause a "frameshift mutation." Remember that the bases are read in groups of three by the tRNA. If the reading frame gets off by one base, the resulting sequence will consist of an entirely different set of codons. The reading of an mRNA is like reading three letter words of a sentence. Imagine you wrote "the big dog ate the red cat". If you take out the second letter from "big", the frame will be shifted so now it will read " the bgd oga tet her edc at." One single deletion makes the whole "sentence" impossible to read.

Many mutations are not caused by errors in replication. Mutations can happen spontaneously and they can be caused by **mutagens** in the environment. Some chemicals, such as those found in tobacco smoke, can be mutagens. Sometimes mutagens can also cause cancer. Tobacco smoke, for example, is often linked to lung cancer.

Lesson Summary

- DNA stores the genetic information of the cell in the sequence of its 4 bases: adenine, thymine, guanine, and cytosine.
- The information in a small segment of DNA, a gene, is sent by mRNA to the ribosome to synthesize a protein.
- Within the ribosome, tRNA reads the mRNA in sets of three bases (triplets), called codons, which encode for the specific amino acids that make up the protein.
- A mutation is a permanent change in the sequence of bases in DNA.

Review Questions

Recall

1. What is a nucleotide made out of?

2. Describe the process of DNA replication.

3. What is made in the process of transcription?

4. What is made in the process of translation?

5. Name a mutagen.

Apply Concepts

6. Translate the following segment of DNA into RNA: AGTTC

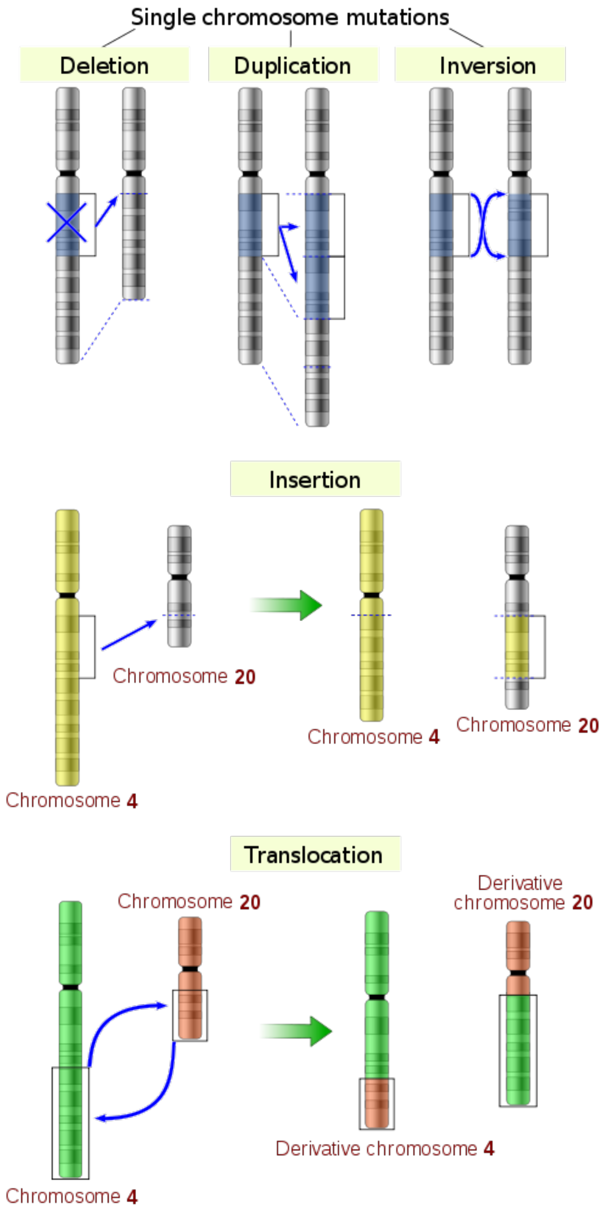


Figure 4.29: Mutations can arise in DNA through deletion, duplication, inversion, insertion, and translocation within the chromosome.

7. Write the complimentary DNA nucleotides to this strand of DNA: GGTCCA
8. Nucleotides are subunits of which two macromolecules?
9. Amino acids are subunits that make up what macromolecule?
10. How does RNA encode for proteins?

Critical Thinking

11. How does a mutation in a strand of DNA affect translation and transcription?
12. Given the DNA sequence, ATGTTAGCCTTA, what is the mRNA sequence? What is the amino acid sequence?

Further Reading / Supplemental Links

- http://nobelprize.org/educational_games/medicine/dna_double_helix/readmore.html
- http://learn.genetics.utah.edu/units/basics/builddna/
- http://enwikipedia.org/
- http://sickle.bwh.harvard.edu/scd_background.html

Points to Consider

- Your cells have "proofreaders" that replace mismatched pairs that occurred during DNA synthesis. How would that affect the rate of mutation in your body?
- There are many diseases due to mutations in the DNA. These are known as genetic diseases, and many can be passed onto the next generation. Think about how a single base change cause a huge medical problem.
- Your DNA contains the instructions to make you. So is everyone's DNA different? Can it be used to distinguish individuals, like a fingerprint?

Image Sources

(1) Onie. http://commons.wikimedia.org/wiki/Image:Codons_aminoacids_table.png. GNU-FDL.

(2) DOE Human Genome Project. < . Public Domain.

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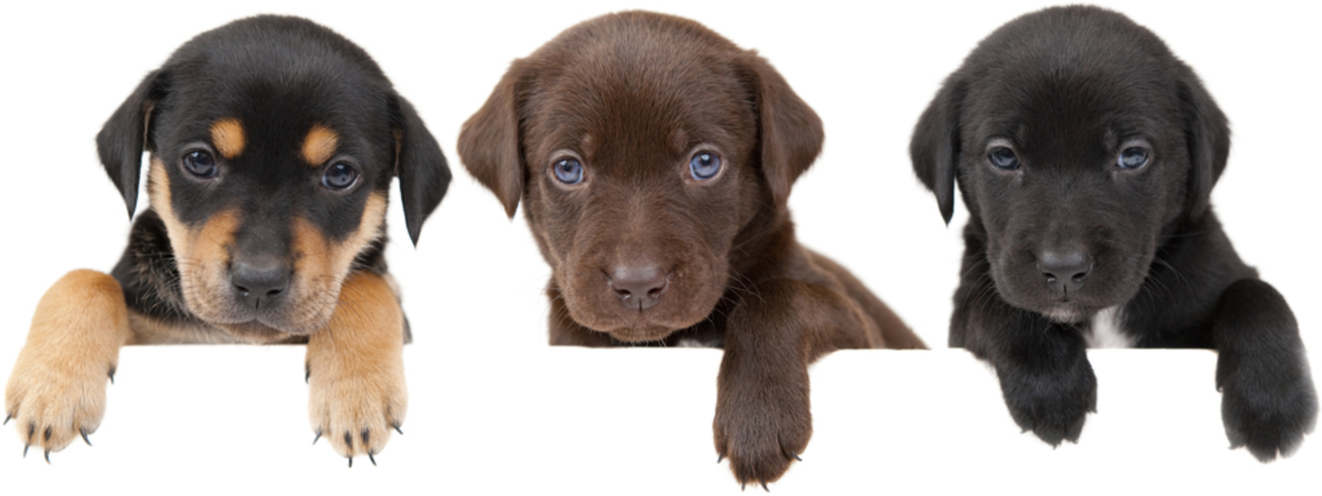
(22) http://commons.wikimedia.org/wiki/Image:Gray9.png. Public Domain.

Chapter 5

MS Genetics



The above puppies are offspring from the same parents. Why don't the puppies look identical to each other? Do you think they are identical to their parents? Or do you think they have some traits from their mother and some from their father?

Just as you don't look exactly like your parents, neither do these puppies. Has anyone ever told you, "You have your father's eyes"? or, "You have red hair like your grandmother; it must have skipped a generation." You don't look identical to your parents or to your grandparents. But many of their traits are passed down to you.

Genetics seeks to answer why and how we, and all living things, inherit traits from the previous generation.

5.1 Gregor Mendel and the Foundations of Genetics

Lesson Objectives

- Explain Mendel's law of segregation.
- Draw a Punnett square to make predictions about the traits of the offspring of a simple genetic cross.

Check Your Understanding

- What is the genetic material of our cells?
- How does meiosis affect the chromosome number in gametes?

Vocabulary

- dominant
- F1 generation
- F2 generation
- genetics
- Punnett square
- recessive

Mendel's Experiments

What does the word ”inherit” mean? You may have inherited something of value from a grandparent or another family member. To inherit is to receive something from someone who came before you. You can inherit objects, but you can also inherit traits. If you inherit a trait from your parents, you can be inheriting their eye color, hair color, or even the shape of your nose and ears!

Genetics is the study of inheritance. The field of genetics seeks to explain how traits are passed on from one generation to the next.

An introduction to heredity can be seen at `http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/12/eEUvRrhmcxM` (17:27).

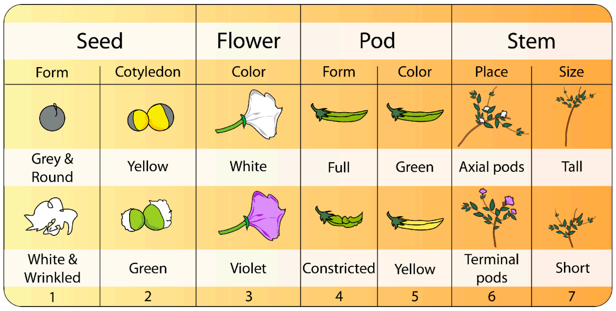
Figure 5.1: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/131

In the late 1850s, an Austrian monk named Gregor Mendel (**Figure** 5.2) performed the first genetics experiments. To study genetics, Mendel chose to work with pea plants because they have easily identifiable traits (**Figure** 5.3). For example, pea plants are either tall or short, which are easily identifiable traits. Pea plants grow quickly, so he could complete many experiments in a short period of time.

Figure 5.2: Gregor Mendel

Mendel also used pea plants because they can either self-pollinate or be cross-pollinated by hand, by moving pollen from one flower to the stigma of another. When one plant's sex cells combine with another plant's sex cells, it is called a "cross." These crosses produce offspring (or children), just like when male and female animals mate. Since Mendel could move pollen between plants, he could carefully observe the results of crosses between two different types of plants.

He studied the inheritance patterns for many different traits in peas, including round seeds versus wrinkled seeds, white flowers versus purple flowers, and tall plants versus short plants. Because of his work, Mendel is considered the "Father of Genetics."



Seed		Flower	Pod		Stem	
Form	Cotyledon	Color	Form	Color	Place	Size
Grey & Round	Yellow	White	Full	Green	Axial pods	Tall
White & Wrinkled	Green	Violet	Constricted	Yellow	Terminal pods	Short
1	2	3	4	5	6	7

Figure 5.3: Characteristics of pea plants.

Mendel's First Experiment

In one of Mendel's early experiments, he crossed a short plant and a tall plant. What do you predict the offspring (children) of these plants were? Medium-sized plants? Most people during Mendel's time would have said medium-sized. But an unexpected result occurred.

Mendel observed that the offspring of this cross (called the **F1 generation**) were all tall plants!

Next, Mendel let the F1 generation self-pollinate. That means the tall plant offspring were crossed with each other. He found that 75% of their offspring (the **F2 generation**) were tall, while 25% were short. Shortness skipped a generation. But why? In all, Mendel studied seven characteristics, with almost 20,000 F2 plants analyzed. All of his results were similar to the first experiment - about three out of every four plants had one trait, while just one out of every four plants had the other.

For example, he crossed purple flowered-plants and white flowered-plants. Do you think the colors blended? No, they did not. Just like the previous experiment, all offspring in this cross (the F1 generation) were one color: purple. In the F2 generation, 75% of plants had purple flowers and 25% had white flowers. There was no blending of traits in any of Mendel's experiments.

An interactive pea plant experiment can be found at `http://sonic.net/~nbs/projects/anthro201/exper/`.

Dominance

Mendel had to come up with a theory of inheritance to explain his results. He developed a theory called "the law of segregation."

He proposed that each pea plant had two hereditary factors for each trait. There were two possibilities for each hereditary factor, such as short or tall. One factor is **dominant** to the other. The other trait that is masked is called the **recessive** factor, meaning that when both factors are present, only the effects of the dominant factor are noticeable.

Each parent can only pass on one of these factors to the offspring. When the sex cells, or gametes (sperm or egg), form, the heredity factors must separate, so there is only one factor per gamete. In other words, the factors are "segregated" in each gamete. When fertilization occurs, the offspring receive one factor from each gamete, so the offspring have two hereditary factors.

This law explains what Mendel had seen in the F1 generation, because the two heredity factors were the short and tall factors. Each individual in the F1 would have one of each factor, and as the tall factor is dominant to the short factor, all the plants appeared tall.

In the F2 generation, produced by the cross of the F1, 25% of the offspring would have two short heredity factors, so they would appear short. 75% would have at least one tall heredity factor and would be tall (see below).

In genetics problems the dominant factor is represented with a capital letter (T) while the recessive factor is represented by a lowercase letter (t). For the T and t factors, three combinations are possible: TT, Tt, and tt. TT plants will be tall, while plants with tt will be short. Since T is dominant to t, plants that are Tt will be tall because the dominant factor masks the recessive factor.

Tall x Short

The above example crosses a TT tall plant with a tt short plant. As each parent gives one factor to the F1 generation, all of the F1 generation will be Tt tall plants. When the F1 are allowed to self-pollinate, each parent will give one factor to the F2 generation. The F2 offspring will be TT, Tt, tT or tt. That is, 75% (3 of 4) tall and 25% (1 of 4) short. A Punnett Square helps determine these possibilities.

Probability and Punnett Squares

If this is confusing, don't worry. A **Punnett Square** is a special tool used to predict the offspring from a cross, or mating between two parents.

An explanation of Punnett squares can be viewed at `http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/13/D5ymMYcLtv0` (25:16).

Video

Figure 5.4: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/133

An example of a Punnett square (**Figure** 5.5) shows the results of a cross between two purple flowers that each have one dominant factor and one recessive factor (Bb).

To create a Punnett Square, perform the following steps:

1. Take the factors from the first parent and place them at the top of the square (B and b)
2. Take the factors from the second parent and line them up on the left side of the square (B and b).
3. Pull the factors from the top into the boxes below.
4. Pull the factors from the side into the boxes next to them.

The possible offspring are represented by the letters in the boxes, with one factor coming from each parent.

Results:

- Top left box: BB, or Purple flowers
- Top right box: Bb, or Purple flowers
- Lower left box: Bb, or Purple flowers
- Lower right box: bb, or White flowers

Only one of the plants out of the four, or 25% of the plants, has white flowers (bb). The other 75% have purple flowers (BB, Bb) because the color purple is the dominant trait in pea plants.

Now imagine you cross one of the white flowers (bb) with a purple flower that has both a dominant and recessive factor (Bb). The only possible gamete in the white flower is the recessive (b), while the purple flower can have gametes with either dominant (B) or recessive (b).

Practice using a Punnett square with this cross (see **Table ??**).

Did you find that 50% of the offspring will be purple and 50% of the offspring will be white?

Practice more Punnett Squares here:

- `http://www.zerobio.com/drag_gr11/mono.htm`

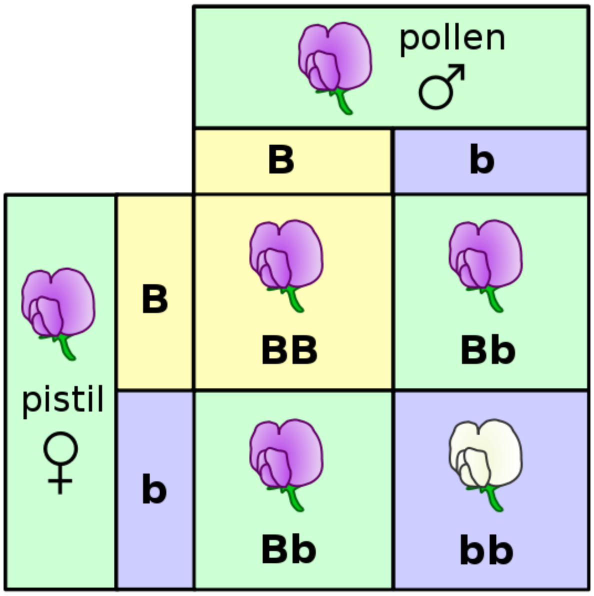


Figure 5.5: The Punnett Square of a cross between two purple flowers (Bb)

- http://www2.edc.org/weblabs/WebLabDirectory1.html

Table 5.1:

	b	b
B	Bb	bb
b	Bb	bb

Table 6.2: The Punnett Square of a white flower (bb) crossed with a purple flower (Bb).

Lesson Summary

- Gregor Mendel is considered the father of genetics, the science of studying inheritance.
- According to Mendel's law of segregation, an organism has two factors for each trait, but each gamete only contains one of these factors.
- A Punnett square is useful for predicting the outcomes of crosses.

Review Questions

Recall

1. What is the term for the offspring of a cross, or the first generation?
2. What is the F2 generation?
3. Who is considered the father of genetics?

Apply Concepts

4. Why did Mendel select peas as a model for studying genetics?
5. What is the difference between a dominant trait and a recessive trait?
6. Why would it be much easier to study genetics in pea plants than in people?

Further Reading / Supplemental Links

- `http://www.mendelweb.org/MWtoc.html`
- `http://www.estrellamountain.edu/faculty/farabee/BIOBK/BioBookgenintro.html`
- `http://sonic.net/~nbs/projects/anthro201/`
- `http://anthro.palomar.edu/mendel/mendel_1.htm`

Points to Consider

- Do you think all traits follow this simple pattern where one factor controls the trait?
- Can you think of other examples where Mendel's laws do not seem to fit?

5.2 Modern Genetics

Lesson Objectives

- Compare Mendel's laws with our modern understanding of chromosomes.
- Explain how codominant traits are inherited.
- Distinguish between phenotype and genotype.
- Explain how polygenic traits are inherited.

Check Your Understanding

- What is a visual representation of a genetic cross?
- What is stated in Mendel's law of segregation?

Vocabulary

- codominance
- genotype
- heterozygous
- homozygous
- phenotype
- polygenic inheritance

Mendel and Modern Genetics

Mendel laid the foundation for modern genetics, but there were still a lot of questions he left unanswered. What exactly are the dominant and recessive factors that determine how all organisms look? And how do these factors work?

Since Mendel's time, scientists have discovered the answers to these questions. Genetic material is made out of DNA. It is the DNA that makes up the hereditary factors that Mendel identified. By applying our modern knowledge of DNA and chromosomes, we can explain Mendel's findings and build on them. In this lesson, we will explore the other connections between Mendel's work and modern genetics.

Traits, Genes, and Alleles

Recall that our DNA is wound into chromosomes. Each of our chromosomes contains a long chain of DNA that encodes hundreds, if not thousands, of genes. Each of these genes can have slightly different versions from individual to individual. These variants of genes are called alleles.

For example, remember that for the height gene in pea plants there are two possible factors. These factors are alleles. There is a dominant allele for tallness (T) and a recessive allele for shortness (t).

Genotype and Phenotype

Genotype is a way to describe the combination of alleles that an individual has for a certain gene (**Table ??**). For each gene, an organism has two alleles, one on each chromosome of a homologous pair of chromosomes (think of it as one allele from mom, one allele from dad). The genotype is represented by letter combinations, such as TT, Tt, and tt.

When an organism has two of the same alleles for a specific gene, it is **homozygous** (homo- means "same") for that gene. An organism can be either homozygous dominant (TT) or homozygous recessive (tt). If an organism has two different alleles (Tt) for a certain gene, it is known as **heterozygous** (hetero- means different).

Table 5.2:

genotype	definition	example
homozygous	two of the same allele	TT or tt
heterozygous	one dominant allele and one recessive allele	Tt
homozygous dominant	two dominant alleles	TT
homozygous recessive	two recessive alleles	tt

Table 6.4: Genotypes

Phenotype is a way to describe the traits you can see. The genotype is like a recipe for a cake, while the phenotype is like the cake made from the recipe. The genotype expresses the phenotype. For example, the phenotypes of Mendel's pea plants were either tall or short, or were purple-flowered or white-flowered.

Can organisms with different genotypes have the same phenotypes? Let's see.

What is the phenotype of a pea plant that is homozygous dominant (TT) for the tall trait? Tall. What is the phenotype of a pea plant that is heterozygous (Tt)? It is also tall. The answer is yes, two different genotypes can result in the same phenotype. Remember, the recessive phenotype will be expressed only when the dominant allele is absent, or when an individual is homozygous recessive (tt) (**Figure** 5.6).

Exceptions to Mendel's Laws: Incomplete Dominance and Codominance

In all of Mendel's experiments, he worked with traits where a single gene controlled the trait. Each also had one allele that was always dominant to the recessive allele. But this is not always true.

There are exceptions to Mendel's rules, and these exceptions usually have something to do with the dominant allele. If you cross a homozygous red flower with a homozygous white flower, according to Mendel's laws, what color flower should result from the cross? Either a completely red or completely white

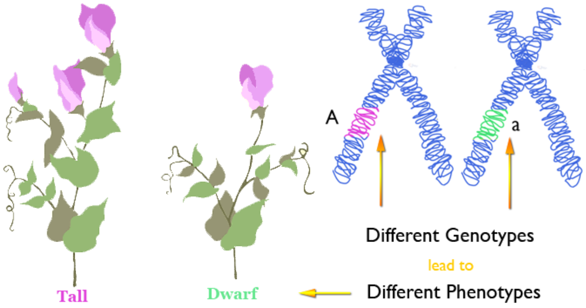


Figure 5.6: Different genotypes (AA, Aa, aa or TT, Tt, tt) will lead to different phenotypes, or different appearances of the organism

flower, depending on which allele is dominant. But since Mendel's time, scientists have discovered this is not always the case.

Incomplete Dominance

One allele is NOT always completely dominant over another allele. Sometimes an individual has a phenotype between the two parents because one allele is not dominant over another. This pattern of inheritance is called **incomplete dominance.** For example, snapdragon flowers show incomplete dominance. One of the genes for flower color in snapdragons has two alleles, one for red flowers and one for white flowers.

A plant that is homozygous for the red allele (RR) will have red flowers, while a plant that is homozygous for the white allele will have white flowers (WW). But the heterozygote will have pink flowers (RW) (**Figure** 5.7). Neither the red nor the white allele is dominant, so the phenotype of the offspring is a blend of the two parents.

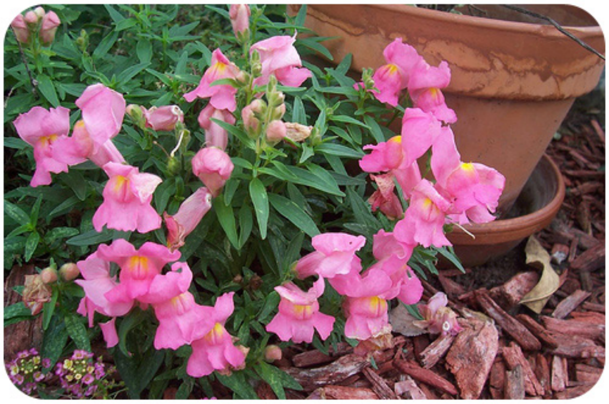


Figure 5.7: Pink snapdragons are an example of incomplete dominance.

Another example of incomplete dominance is sickle cell anemia, a disease in which a blood protein called hemoglobin is produced incorrectly, causing the red blood cells to have a sickle shape. A person that is homozygous recessive (ss) for the sickle cell trait will have red blood cells that all have the incorrect hemoglobin. A person who is homozygous dominant (SS) will have normal red blood cells.

What type of blood cells do you think a person who is heterozygous (Ss) for the trait will have? They will have some misshapen cells and some normal cells (**Figure** 5.8). Both the dominant and recessive alleles are expressed, so the result is a phenotype that is a combination of the recessive and dominant traits.

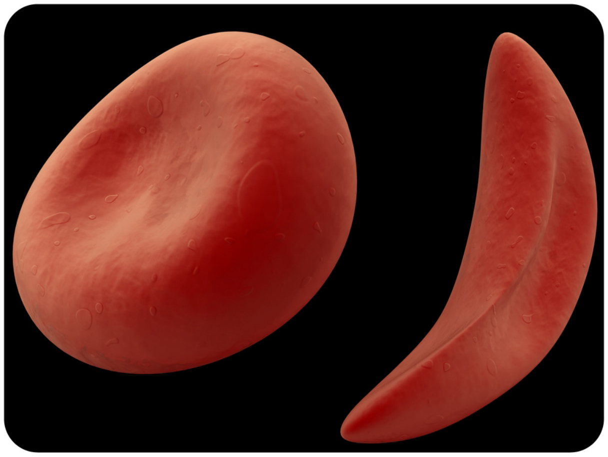


Figure 5.8: Sickle cell anemia causes red blood cells to become misshapen and curved (right cell) unlike normal, rounded red blood cells (left cell).

Codominance

Another exception to Mendel's laws is a called **codominance.** For example, our blood type shows codominance. Do you know what your blood type is? Are you A? O? AB? Those letters actually represent alleles. Unlike other traits, your blood type has 3 alleles, instead of 2!

The ABO blood types (**Figure** 5.9) are named for the protein, or antigen, attached to the outside of the blood cell. An antigen is a substance that provokes an immune response, your body's defenses against disease, which will be discussed further in the *Diseases and the Body's Defenses* chapter.

In this case, two alleles are dominant and completely expressed (I^A and I^B), while one allele is recessive (*i*). The I^A allele encodes for red blood cells with the A antigen, while the I^B allele encodes for red blood cells with the B antigen. The recessive allele (*i*) doesn't encode for any proteins. Therefore a person with two recessive alleles (*ii*) has type O blood. As no dominant (I^A and I^B) allele is present, the person cannot have type A or type B blood.

There are two possible genotypes for type A blood, homozygous (I^AI^A) and heterozygous (I^Ai), and two possible genotypes for type B blood, (I^BI^B and I^Bi). If a person is heterozygous for both the I^A and I^B alleles, they will express both and have type AB blood with both antigens on each red blood cell.

This pattern of inheritance is significantly different than Mendel's rules for inheritance because both alleles are expressed completely and one does not mask the other.

Polygenic Traits and Environmental Influences

Another exception to Mendel's rules is polygenic inheritance, which occurs when a trait is controlled by more than one gene. This means that each dominant allele "adds" to the expression of the next dominant allele.

Usually, traits are polygenic when there is wide variation in the trait. For example, humans can be many different sizes. Height is a polygenic trait. If you are dominant for all of the alleles for height, then you will be very tall. There is also a wide range of skin color across people. Skin color is also a polygenic trait.

Polygenic inheritance often results in a bell shaped curve when you analyze the population (**Figure** 5.10). That means that most people fall in the middle of the phenotypic range, such as average height, while very few people are at the extremes, such as very tall or very short.

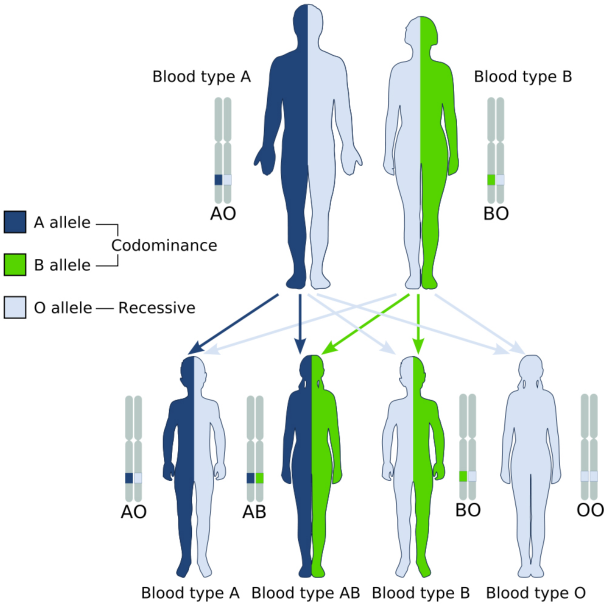


Figure 5.9: An example of codominant inheritance is ABO blood types.

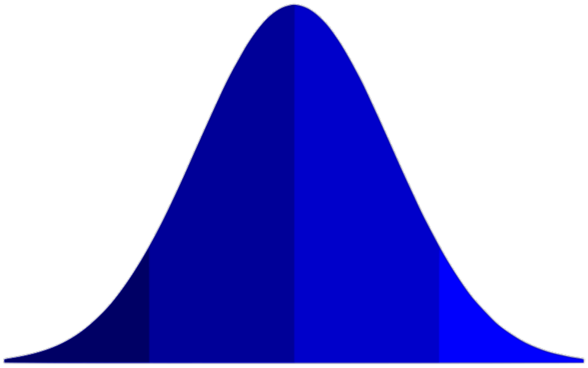


Figure 5.10: Polygenic traits tend to result in a distribution that resembles a bell-shaped curve, with few at the extremes and most in the middle. There may be 4 or 6 or more alleles involved in the phenotype. At the left extreme, individuals are completely dominant for all alleles, and at the other extreme, individuals are completely recessive for all alleles. Individuals in the middle have various combinations of recessive and dominant alleles.

Lesson Summary

- Variants of genes are called alleles.
- Genotype is the combination of alleles that an individual has for a certain gene, while phenotype is the appearance caused by the expression of the genotype.
- Incomplete dominance and codominance do not fit Mendel's rules because one allele does not entirely mask the other.
- In polygenic inheritance, many genes control a trait. Each dominant allele adds to the next dominant allele.

Review Questions

Recall

1. What is a variant of a gene that occurs at the same place on homologous chromosomes?

2. What is the type of allele that only affects the phenotype in the homozygous condition?

3. What type of allele masks the expression of the recessive allele?

4. What is the term for the specific alleles of an individual for a particular trait?

5. What is the term for the appearance of the organism, as determined by the genotype?

Apply Concepts

6. If two individuals have a certain phenotype, such as tall pea plants, does that mean they must have the same genotype?

7. What is the term for the pattern of inheritance where an individual has an intermediate phenotype between the two parents?

8. What is the inheritance pattern where both alleles are expressed?

Think Critically

9. IQ in humans varies, with most people having an IQ of around 100, and with a few people at the extremes, such as 50 or 150. What type of inheritance do you think this might describe?

10. A dark purple flower is crossed with a white flower of the same species and the offspring have light purple flowers. What type of inheritance does this describe? Explain.

Further Reading / Supplemental Links

- `http://en.wikipedia.org/wiki/Dominant_gene`
- `http://en.wikipedia.org/wiki/Polygenic_inheritance`
- `http://staff.jccc.net/pdecell/evolution/polygen.html`
- `http://www.curiosityrats.com/genetics.html`
- `http://www.estrellamountain.edu/faculty/farabee/BIOBK/BioBookgenintro.html`
- `http://www.physorg.com/news188148947.html`

Points to Consider

- Hypothesize about the genetic differences between males and females.
- Can you name any human genetic disorders?
- If a baby inherits an extra chromosome, what might the result be?

5.3 Human Genetics

Lesson Objectives

- List the two types of chromosomes in the human genome.
- Predict patterns of inheritance for traits located on the sex chromosomes.
- Describe how some common human genetic disorders are inherited.
- Explain how changes in chromosomes can cause disorders in humans.

Check Your Understanding

- How many alleles does an individual have for each gene/trait?
- How do we predict the probability of traits being passed on to the next generation?
- What do we call complexes of DNA wound around proteins that pass on genetic information to the next generation of cells?

Vocabulary

- autosomes
- pedigree
- sex-linked inheritance
- sex-linked trait

Special Inheritance Patterns

What gene determines if a baby is male or female? How are humans born with genetic disorders, like cystic fibrosis or Down Syndrome? We can apply Mendel's rules to describe how many human traits and genetic disorders are inherited.

We can now also explain special inheritance patterns that don't fit Mendel's rules.

Sex-linked Inheritance

What determines if a baby is a male or female? Recall that you have 23 pairs of chromosomes— and one of those pairs is the sex chromosomes. Everyone has two sex chromosomes, X or Y. Females have two X chromosomes (XX), while males have one X chromosome and one Y chromosome (XY).

If a baby inherits an X from the father and an X from the mother, what will be the child's sex? Female. If the father's sperm carries the Y chromosome, the child will be male. Notice that a mother can only pass on an X chromosome, so the sex of the baby is determined by the father. The father has a 50 percent chance of passing on the Y or X chromosome, so there is a 50 percent chance that a child will be male, and a 50 percent chance a child will be female.

One special pattern of inheritance that doesn't fit Mendel's rules is **sex-linked inheritance,** referring to the inheritance of traits that are located on genes on the sex chromosomes. Since males and females do not have the same sex chromosomes, there will be differences between the sexes in how these **sex-linked traits** — traits linked to genes located on the sex chromosomes — are expressed.

One example of a sex-linked trait is red-green colorblindness. People with this type of colorblindness cannot tell the difference between red and green. They often see these colors as shades of brown (see **Figure** 5.11 and **Table** 5.3). Boys are much more likely to be colorblind than girls. This is because colorblindness is a sex-linked recessive trait.

Boys only have one X chromosome, so if that chromosome carries the gene for colorblindness, they will be colorblind. As girls have two X chromosomes, a girl can have one X chromosome with the colorblind gene and one X chromosome with a normal gene for color vision. Since colorblindness is recessive, the dominant normal gene will mask the recessive colorblind gene. Females with one colorblindness allele and one normal allele are referred to as carriers. They carry the allele but do not express it.

How would a female become color-blind? She would have to inherit two genes for colorblindness, which is very unlikely. Many sex-linked traits are inherited in a recessive manner.

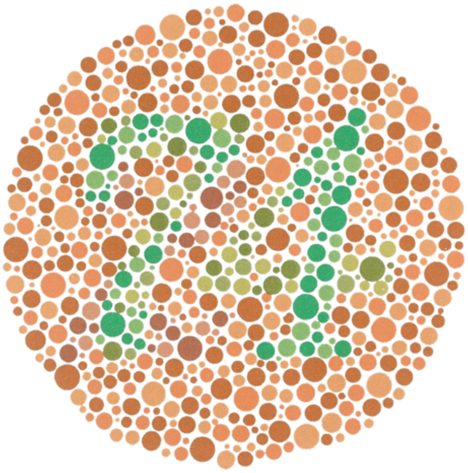


Figure 5.11: A person with red-green colorblindness would not be able to see the number.

Table 5.3:

	X^c	**X**
X	**X^cX** (carrier female)	**XX** (normal female)
Y	**X^cY** (colorblind male)	**XY** (normal male)

Table 6.6: According to this Punnett square, the son of a woman who carries the colorblindness trait and a normal male has a 50% chance of being colorblind.

Human Genetic Disorders

Some human genetic disorders are also X-linked or Y-linked, which means the faulty gene is carried on these sex chromosomes. Other genetic disorders are carried on one of the other 22 pairs of chromosomes; these chromosomes are known as **autosomes** or autosomal (non-sex) chromosomes.

Autosomal Recessive Disorders

Some genetic disorders are caused by recessive or dominant alleles of a single gene on an autosome. An example of an autosomal recessive genetic disorder is cystic fibrosis. Children with cystic fibrosis have excessively thick mucus in their lungs, which makes it difficult for them to breathe. The inheritance of this recessive allele is the same as any other recessive allele, so a Punnett square can be used to predict the probability that two carriers of the disease will have a child with cystic fibrosis.

What are the possible genotypes of the offspring in **Table** 5.4? What are the possible phenotypes?

Table 5.4:

	F	**f**
F	**FF** (normal)	**Ff** (carrier)
f	**Ff** (carrier)	**ff** (affected)

According to this Punnett square, two parents that are carriers of cystic fibrosis gene have a 25% chance of having a child with cystic fibrosis.

Automsomal Dominant Disorders

Huntington's disease is an example of an autosomal dominant disorder. This means that if the dominant allele is present, then the person will express the disease.

The disease causes the brain's cells to break down, leading to muscle spasms and personality changes. Unlike most other genetic disorders, the symptoms usually do not become apparent until middle age. You can use a simple Punnett square to predict the inheritance of a dominant autosomal disorder, like Huntington's disease. If one parent has Huntington's disease, what is the chance of passing it on to their children? If you draw the Punnett square, you will find that there is a 50 percent chance of the disorder being passed on to the children.

Pedigree Analysis

A **pedigree** is a chart which shows the inheritance of a trait over several generations. A pedigree is commonly created for families, and it outlines the inheritance patterns of genetic disorders.

Figure 5.12 shows a pedigree displaying recessive inheritance of a disorder through three generations. From studying a pedigree, scientists can determine the following:

- If the trait is sex-linked (on the X or Y chromosome) or autosomal (on a chromosome that does not determine sex)
- If he trait is inherited in a dominant or recessive fashion, and possibly whether individuals with the trait are heterozygous or homozygous.

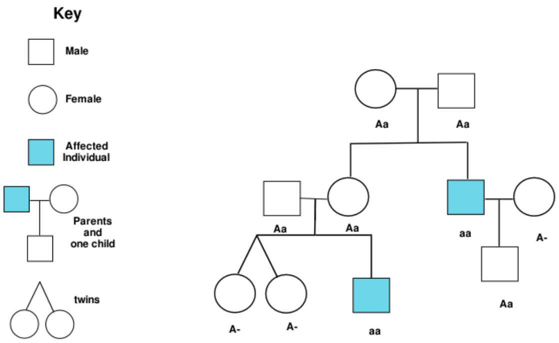


Figure 5.12: In a pedigree, squares symbolize males, and circles represent females. A horizontal line joining a male and female indicates that the couple had offspring. Vertical lines indicate offspring which are listed left to right, in order of birth. Shading of the circle or square indicates an individual who has the trait being traced. The inheritance of the recessive trait is being traced. "A" is the dominant allele and "a" is the recessive allele.

Pedigree analysis is discussed in `http://www.youtube.com/watch?v=HbIHjsn5cHo` (9:13).

Figure 5.13: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/141

Chromosomal Disorders

Some children are born with genetic defects that are not carried by a single gene. Instead, an error in a larger part of the chromosome or even in an entire chromosome causes the disorder. Usually the error happens when the egg or sperm is forming. Having extra chromosomes or damaged chromosomes can also cause disorders.

Extra Chromosomes

One common example of an extra-chromosome disorder is Down syndrome (**Figure** 5.14 and **Figure** 5.15). Children with Down syndrome are mentally disabled and also have physical deformities. Down syndrome occurs when a baby receives an extra chromosome from one of his or her parents. Usually, a child will receive one chromosome 21 from the mother and one chromosome 21 from the father. In an individual with Down syndrome, however, there are three copies of chromosome 21. Down syndrome is therefore also known as Trisomy 21.

Figure 5.14: A child with Down syndrome.

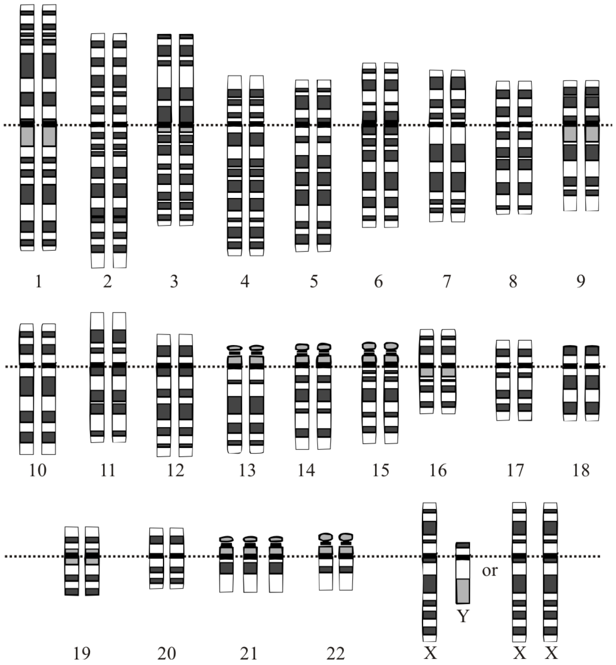


Figure 5.15: Karyotype of Down Syndrome. Notice the extra chromosome 21.

Another example of a chromosomal disorder is Klinefelter syndrome, in which a male inherits an extra "X" chromosome. These individuals have underdeveloped sex organs and elongated limbs, and have difficulty learning new things.

Outside of chromosome 21 and the sex chromosomes, most embryos with extra chromosomes do not usually survive. Because chromosomes carry many, many genes, a disruption of a chromosome can cause severe problems with the development of a fetus.

Damaged Chromosomes

Chromosomal disorders also occur when part of a chromosome becomes damaged. For example, if a tiny portion of chromosome 5 is missing, the individual will have *cri du chat* (cat's cry) syndrome. These individuals have misshapen facial features and the infant's cry resembles a cat's cry.

Lesson Summary

- Some human traits are controlled by genes on the sex chromosomes.
- Human genetic disorders can be inherited through recessive or dominant alleles, and they can be located on the sex chromosomes or autosomes (non-sex).
- Changes in chromosome number can lead to disorders like Down syndrome.

Review Questions

Recall

1. How many chromosomes do you have in each cell of your body?

Apply Concepts

2. How is Down's syndrome inherited?

Think Critically

3. A son cannot inherit colorblindness from his father. Why not?

4. One parent is a carrier of the cystic fibrosis gene, while the other parent does not carry the allele. Can their child have cystic fibrosis?

Further Reading / Supplemental Links

- `http://www.articlesbase.com/health-articles/what-is-haemophilia-412305.html`
- `http://geneticdisorderinfo.wikispaces.com/`
- `http://www.hhmi.org/biointeractive/vlabs/cardiology/index.html`

Points to Consider

- Human cloning is illegal in many countries. Do you agree with these restrictions?
- Why would it be helpful to know all the genes that make up human DNA?
- It may be possible in the future to obtain the sequence of all your genes. Would you want to take advantage of this opportunity? Why or why not?

5.4 Genetic Advances

Lesson Objectives

- Explain how clones are made.
- Explain how vectors are made.
- Explain what sequencing a genome tells us.
- Describe how gene therapy works.

Check Your Understanding

- What part of the cell contains the genetic material?
- What are the base pairing rules for DNA?

Vocabulary

- cloning
- gene therapy
- Human Genome project
- plasmid
- recombinant DNA
- somatic cell
- transformation
- vector

Biotechnology and DNA Technology

Since Mendel's time, there have been many changes in the understanding of genetics. As scientists learn more about how DNA works, they can develop technologies that allow us to reveal the genetic secrets encoded in our DNA and even alter an organism's DNA.

Genetic engineering (also known as "biotechnology" or "DNA technology") helps us better understand and predict the inheritance of genetic diseases, treat these diseases, produce new medicines, and even produce new food products.

Biotechnology: An Introduction can be viewed at `http://www.youtube.com/watch?v=nnSYigHofb0&#38;feature=related` (1:05).

Figure 5.16: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/600

Recombinant DNA

Recombinant DNA is the combination of DNA from two different sources. For example, it is possible to place a human gene into bacterial DNA. Recombinant DNA technology is useful in gene cloning and in identifying the function of a gene, as well as producing useful proteins, such as insulin. To treat diabetes, many people need insulin. Previously, insulin had been taken from animals. Through recombinant DNA technology, bacteria were created that carry the human gene which codes for the production of insulin. These bacteria become tiny factories that produce this protein. Recombinant DNA technology helps create insulin so it can be used by humans.

A clone is an exact copy. Below are the steps used to copy, or clone, a gene:

1. A gene or piece of DNA is put in a **vector**, or carrier molecule, producing a recombinant DNA molecule.
2. The vector is placed into a host cell, such as a bacterium.
3. The gene is copied (or cloned) inside of the bacterium. As the bacterial DNA is copied, so is the vector DNA. As the bacteria divide, the recombinant DNA molecules are divided between the new cells. Over a 12 to 24 hour period, millions of copies of the cloned DNA are made.
4. The cloned DNA can produce a protein (like insulin) that be used in medicine or in research.

Bacteria have small rings of DNA in the cytoplasm, called **plasmids** (**Figure** 5.17). When putting foreign DNA into a bacterium, the plasmids are often used as a vector. Viruses can also be used as vectors. Try inserting DNA into a fly embryo here: `http://www.hhmi.org/biointeractive/vlabs/transgenic_fly/index.html`.

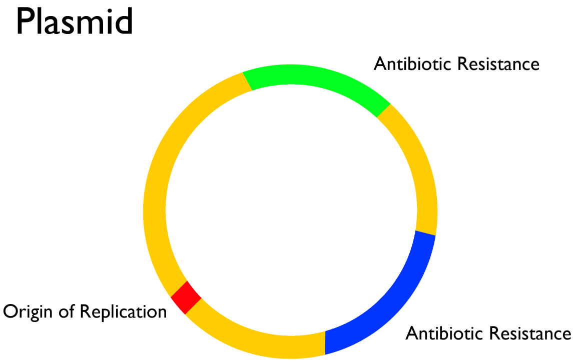


Figure 5.17: This image shows a drawing of a plasmid. The plasmid has two large segments and one small segment depicted. The two large segments (green and blue) indicate antibiotic resistances usually used in a screening procedure, and the small segment (red) indicates an origin of replication. The origin of replication is where DNA replication starts, copying the plasmid. The antibiotic resistance segments ensure only bacteria with the plasmid will grow.

Cloning

Cloning is the process of creating an exact replica of an organism. The clone's DNA is exactly the same as the parent's DNA. Bacteria and plants have long been able to clone themselves through asexual reproduction. In animals, however, cloning does not happen naturally. In 1997, that all changed when a sheep named Dolly was the first mammal ever to be successfully cloned. Other animals can now also be cloned in a laboratory.

The process of producing an animal like Dolly starts with a single cell from the animal that is going to be cloned. Below are the steps involved in the process of cloning:

1. In the case of Dolly, cells from the mammary glands were taken from the adult that was to be cloned. But other somatic cells can be used. **Somatic cells** come from the body and are not gametes like sperm or egg.
2. The nucleus is removed from this cell.
3. The nucleus is placed in a donor egg that has had its nucleus removed.
4. The new cell is stimulated with an electric shock and embryo development begins, as if it were a normal zygote.
5. The resulting embryo is implanted into a mother sheep, where it continue its development. This process is shown in **Figure** 5.18.

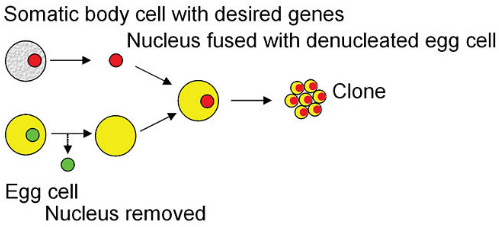

Somatic body cell with desired genes
Nucleus fused with denucleated egg cell
Clone
Egg cell
Nucleus removed

Figure 5.18: To clone an animal, a nucleus from the animal's cells are fused with an egg cell (from which the nucleus has been removed) from a donor.

Is Cloning Easy?

Cloning is not always successful. Most of the time, this cloning process does not result in a healthy adult animal. The process has to be repeated many times until it works. In fact, 277 tries were needed to produce Dolly. This high failure rate is one reason that human cloning is banned in the United States. In order to produce a cloned human, many attempts would result in the surrogate mothers experiencing miscarriages, stillbirths, or deformities in the infant. There are also many additional ethical considerations related to human cloning. Can you think of reasons why people are for or against cloning?

Human Genome Project

A person's genome is all of his or her genetic information; in other words, the human genome is all the information that makes us human.

The **Human Genome Project** (**Figure** 5.19) was an international effort to sequence all 3 billion bases that make up our DNA and to identify within this code more than 20,000 human genes. Scientists also completed a chromosome map, identifying where the genes are located on each of the chromosomes. The Human Genome Project was completed in 2003. Though the Human Genome Project is finished, analysis of the data will continue for many years.

Exciting applications of the Human Genome Project include the following:

- The genetic basis for many diseases can be more easily determined, and now there are tests for over 1,000 genetic disorders.

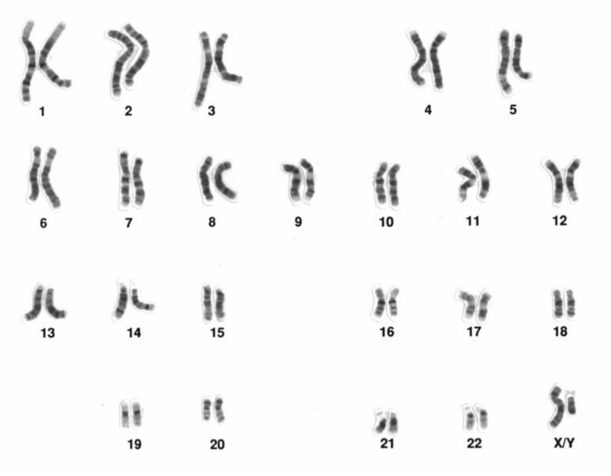


Figure 5.19: To complete the Human Genome Project, all 23 pairs of chromosomes in the human body were sequenced. Each chromosome contains thousands of genes. This is a karyotype, a visual representation of an individual's chromosomes lined up by size.

- The technologies developed during this effort, and since the completion of this project, will reduce the cost of sequencing a person's genome. This may eventually allow many people to sequence their individual genome.
- Analysis of your own genome could determine if you are at risk for specific diseases.
- Knowing you might be genetically prone to a certain disease would allow you to make preventive lifestyle changes or have medical screenings.

The Human Genome Project. Exploring Our Molecular Selves can be viewed at `http://www.youtube.com/watch?v=VJycRYBNtwY&#38;feature=related` (3:41).

Figure 5.20: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/601

Gene Therapy

Gene therapy is the insertion of genes into a person's cells to cure a genetic disorder. Though gene therapy is still in experimental stages, the common use of this therapy may occur during your lifetime.

There are two main types of gene therapy:

1. One done inside the body (*in vivo*)
2. One done outside the body (*ex vivo*)

In Vivo Gene Therapy

During *in vivo* gene therapy, done inside the body, the vector with the gene of interest is introduced directly into the patient and taken up by the patient's cells. For example, cystic fibrosis gene therapy is targeted at the respiratory system, so a solution with the vector can be sprayed into the patient's nose. Recently, *in vivo* gene therapy was also used to partially restore the vision of three young adults with a rare type of eye disease.

Ex Vivo Gene Therapy

In *ex vivo* gene therapy, done outside the body, cells are removed from the patient and the proper gene is inserted using a virus as a vector. The modified cells are placed back into the patient.

One of the first uses of this type of gene therapy was in the treatment of a young girl with a rare genetic disease, adenosine deaminase deficiency, or ADA deficiency. People with this disorder are missing the ADA enzyme, which breaks down a toxin called deoxyadenosine. If the toxin is not broken down, it accumulates and destroys immune cells. As a result, individuals with ADA deficiency do not have a healthy immune system to fight off infections. In the gene therapy treatment for this disorder, bone marrow stem cells were taken from the girl's body and the missing gene was inserted in these cells outside the body. Then the modified cells were put back into her bloodstream. This treatment successfully restored the function of her immune system, but only with repeated treatments.

Biotechnology in Agriculture

Biotechnology has also led scientists to develop useful applications in agriculture and food science. These include the development of transgenic crops - the placement of genes into plants to give the crop a beneficial trait. Benefits include:

- Improved yield from crops.
- Reduced vulnerability of crops to environmental stresses.
- Increased nutritional qualities of food crops.
- Improved taste, texture or appearance of food.
- Reduced dependence on fertilizers, pesticides and other chemicals.

Crops are obviously dependent on environmental conditions. Drought can destroy crop yields, as can too much rain or floods. But what if crops could be developed to withstand these harsh conditions?

Biotechnology will allow the development of crops containing genes that will enable them to withstand harsh conditions. For example, drought and salty soil are two significant factors affecting crop productivity. But there are crops that can withstand these harsh conditions. Why? Probably because of that plant's genetics. So scientists are studying plants that can cope with these extreme conditions, trying to identify and isolate the genes that control these beneficial traits. The genes could then be transferred into more desirable crops, with the hope of producing the same phenotypes in those crops.

Thale cress (**Figure** 5.21), a species of *Arabidopsis (Arabidopsis thaliana)*, is a tiny weed that is often used for plant research because it is very easy to grow and its DNA has been mapped.

Scientists have identified a gene from this plant, At-DBF2, that gives the plant resistance to some environmental stresses. When this gene is inserted into tomato and tobacco cells, the cells were able to withstand environmental stresses like salt, drought, cold and heat far better than ordinary cells. If these results prove successful in larger trials, then At-DBF2 genes could help in engineering crops that can better withstand harsh environments.

Figure 5.21: Thale cress (Arabidopsis thaliana).

Lesson Summary

- Using recombinant DNA technology, a foreign gene can be inserted into an organism's DNA.
- Cloning of mammals is still being perfected, but several cloned animals have been created by implanting the nucleus of a somatic cell into a cell in which the nucleus has been removed.
- The Human Genome Project produced a genetic map of all the human chromosomes and determined the sequence of every base pair in our DNA.
- Gene therapy involves treating an illness caused by a defective gene through the use of a vector to integrate a normal copy of the gene into the patient.

Review Questions

Recall

1. What is the term for all the genetic information of the human species?
2. What are the rings of accessory DNA in bacteria that are often used as a vector in genetic engineering?
3. What is the term for producing identical copies of an organism?
4. What is the vehicle used to introduce foreign DNA into an organism?

Apply Concepts

5. What supplies the cytoplasm of the clone's cells during the cloning of an organism?
6. What is one application of recombinant DNA technology?
7. Can gene therapy cure a disease caused by a virus?

Critical Thinking

8. What are the benefits of having access to your entire genetic code? What are the possible problems?
9. Should human cloning be legal in the US? Why or why not?

Further Reading / Supplemental Links

- http://www.ornl.gov/sci/techresources/Human_Genome/home.shtml
- http://history.nih.gov/exhibits/genetics/sect4.htm
- http://learn.genetics.utah.edu/units/disorders/whataregd/ada/
- http://www.lifesitenews.com/ldn/2007/nov/07112003.html
- http://www.le.ac.uk/ge/genie/vgec/sc/genomics.html
- http://en.wikipedia.org/wiki/Recombinant_DNA

Points to Consider

Next we begin to discuss evolution, the change in species over time.

- Fossils provide evidence of evolution, but what is a fossil?
- If two animals are similar in structure, would you guess they are closely related? Why or why not?

Image Sources

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Chapter 6

MS Life Science Glossary

A

abiotic Physical (nonliving) properties of an organism's environment, such as sunlight, climate, soil, water and air.

ABO blood type system Blood group system that is determined by the presence or absence of certain molecules, called antigens, on the surface of red blood cells (RBCs); there are four blood types in the ABO system: A, B, AB, and O.

abscisic acid Plant hormone involved in maintaining dormancy and closing the stomata.

absorption Process in which substances are taken up by the blood; after food is broken down into small nutrient molecules, the molecules are absorbed by the blood.

acid rain Precipitation or deposits with a low (acidic) pH.

acquired trait A feature that an organism gets during its lifetime in response to the environment (not from genes); not passed on to future generations through gene

active transport The movement of a molecule from an area of lower concentration to an area of higher concentration; requires a carrier protein and energy.

adaptation A beneficial trait that helps an organism survive in its environment.

adolescence Period of life between the start of puberty and the beginning of adulthood.

aerobic exercises Types of exercises that cause the heart to beat faster and allow the muscles to obtain energy to contract by using oxygen.

aerobic respiration Cellular respiration in the presence of oxygen.

aerofoil A surface which is designed to aid in lifting or controlling by making use of the air currents through which it moves.

AIDS Acquired immune deficiency syndrome, which is a fatal condition caused by the human immunodeficiency virus (HIV).

alcoholic fermentation Fermentation in the absence of oxygen; produces ethyl alcohol (drinking alcohol) and carbon dioxide; occurs in yeasts.

algal bloom Excessive growth of aquatic vegetation or phytoplankton as a result of eutrophication.

allele An alternative form of a gene.

allergen A substance that triggers an allergy.

allergy A condition that occurs when the immune system attacks a harmless foreign substance.

allopatric speciation Speciation that occurs when groups from the same species are geographically isolated physically for long periods.

alternation of generations A lifecycle that alternates between a haploid gametophyte and a diploid sporophyte; characteristic of plants.

altricial Newborn that are helpless at birth and require much parental care.

alveoli Little *sacs* at the end of the bronchioles where most of the gas exchange occurs.

amino acid The units that combine to make proteins.

amniotes Vertebrates whose embryos are surrounded by an amniotic membrane.

amniotic sac Fluid-filled membrane that surrounds and protects a fetus within the uterus.

anaerobic exercise Types of exercises that involve short bursts of high-intensity activity; forces the muscles to obtain energy to contract without using oxygen.

anaerobic respiration Cellular respiration in the absence of oxygen; fermentation.

anaphase Third phase of mitosis and meiosis (anaphase I and anaphase II) where sister chromatids separate and move to opposite sides of the cell.

angina Chest pain caused by the lack of oxygen to the heart muscle; can happen during times of stress or physical activity.

angiosperms Plants with vascular tissue, seeds, and flowers.

animal behavior Any way that animals act, either alone or with other animals.

anther The pollen-containing structure in a flower.

antibody Protein that identifies pathogens or other substances as being harmful; can destroy pathogens by attaching to the cell membrane of the pathogen.

antidiuretic hormone (ADH) Hormone that controls the absorption of water back into blood.

antigen Any protein that triggers an immune response; usually a foreign protein, unlike any protein that the body makes.

anvil Second of three tiny bones that pass vibrations through the ear.

apical dominance Suppressing the growth of the side branches of a plant.

applied science The application of science to practical problems.

aquaculture The raising of aquatic plants and animals, especially seaweed, shellfish and other fish.

aquatic biomes Biomes divided into freshwater and marine biomes and defined according to different physical and ecological factors.

Archaea Microscopic one-celled organisms with no nucleus that tend to live in extreme environments.

arteries Blood vessels that carry blood away from the heart.

artificial selection Occurs when humans select which plants or animals to breed to pass specific traits on to the next generation.

asexual reproduction A form of reproduction in which a new individual is created by only one parent.

asthma A chronic illness in which the bronchioles are inflamed and become narrow.

atherosclerosis A chronic inflammation of the walls of arteries that causes swelling and a buildup of material called plaque.

atom The simplest and smallest particle of matter that still retains the physical and chemical properties of the element; the building block of all matter.

atomic number The number of protons in an element.

ATP A usable form of energy inside the cell; adenosine triphosphate.

atrioventricular (AV) valves Valves that stop blood from moving from the ventricles back into the atria.

atrium One of the two small, thin-walled chambers on the top of the heart that blood first enters.

autoimmune disease A disease that occurs when the immune system attacks the body's own cells.

autonomic nervous system Part of the motor division that carries nerve impulses to internal organs and glands.

autosomes The chromosomes other than the sex chromosomes.

autotroph Organism that produces complex organic compounds from simple inorganic molecules using a source of energy such as sunlight.

auxin Plant hormone involved in tropisms and apical dominance.

axon Part of a neuron that receives nerve impulses from the cell body and passes them on to other cells.

B

bacilli Rod-shaped bacteria or archaea.

bacteria Microscopic one-celled prokaryotic organisms (without a nucleus).

ball and socket joint Joint structure in which the ball-shaped surface of one bone fits into the cuplike depression in another bone; examples include the shoulder and hip joints.

barbel A thin fleshy structure on the external part of the head, such as the jaw, mouth or nostrils, of certain fishes.

basic science Research whose goal is just to find out how the world works, not to solve an urgent problem. Basic research is the source of most new scientific information and nearly all new theories.

behavioral isolation The separation of a population from the rest of its species due to some behavioral barrier, such as having different mating seasons.

bilateral symmetry Body plan in which the left and right side are mirror images.

binary fission An asexual form of reproduction where a cell splits into two daughter cells.

binomial nomenclature The system for naming species in which the first word is the genus and the second word is the species.

biodiversity The number of different species or organisms in an ecological unit (i.e. biome or ecosystem).

biogeochemical cycles The pathway of elements like carbon and nitrogen through the non-living and living parts of the ecosystem.

biohazard Any biological material, such as infectious material that poses a potential to human health, animal health, or the environment.

biological clock Tiny structure in the brain that controls circadian rhythms.

biome A large community of plants and animals that live in the same place.

biosphere The part of the planet and atmosphere with living organisms.

biotic Biological (living) properties of an environment, i.e., the living organisms in a habitat.

birth rate Number of births per individual within the population per unit time.

blood A body fluid that is a type of connective tissue; moves oxygen and other compounds throughout the body.

blood clotting The complex process by which blood forms solid clots.

blood pressure The force exerted by circulating blood on the walls of blood vessels.

bone marrow Soft connective tissue found inside many bones; site of blood cell formation.

brain Control center of the nervous system that is located inside the skull.

brain stem Part of the brain that controls basic body functions, such as breathing, heartbeat, and digestion.

breast cancer Most common type of cancer in females; occurs when cells of the breast grow out of control and form a tumor.

bronchitis An inflammation of the bronchi.

budding Asexual reproduction in which part of the body of a fungus, for example, grows and breaks off, eventually becoming a new organism.

C

calorie Unit used to measure the energy in food.

calyx The sepals collectively; outermost layer of the flower.

Cambrian explosion A sudden burst of evolution that may have been triggered by an environmental change(s); made the environment more suitable for a wider variety of life forms; occurred during the Cambrian Period.

camouflage An appearance which helps a species blend into the background.

cancer A disease in which abnormal cells divide out of control.

capillaries The smallest and narrowest blood vessels in the body.

carapace The thick dorsal shield seen in many crustaceans; often forms a protective chamber for the gills.

carbohydrate Nutrient that include sugars, starches, and fiber; give your body energy; class of organic compound.

carcinogen Anything that can cause cancer.

cardiac muscle An involuntary and specialized kind of muscle found only in the heart.

cardiovascular disease (CVD) Any disease that affects the cardiovascular system, although the term is usually used to describe diseases that are linked to atherosclerosis.

cardiovascular system The organ system that is made up of the heart, the blood vessels, and the blood.

carnivore An organism that eats other animals.

carpel *Female* portion of the flower; consists of stigma, style, and ovary.

carrying capacity Maximum population size that can be supported in a particular area without degradation of the habitat.

cartilage Smooth covering found at the end of bones; made of tough collagen protein fibers; creates smooth surfaces for the easy movement of bones against each other.

cartilaginous skeleton A skeleton made of bone-like material called cartilage.

cell The smallest living unit of life; the smallest unit of structure and function of living organisms.

cell body Part of a neuron that contains the nucleus and other organelles.

cell cycle Phases in the ”life” of eukaryotic cells that leads to cell division.

cell theory All organisms are composed of cells; cells are the basic units of structure and function in an organism; cells only come from preexisting cells.

cellular respiration The process in which the energy in food is converted into energy that can be used by the body’s cells; in other words, glucose is converted into ATP.

cell wall Provides strength and protection for the cell; found around plant, fungal, and bacterial cells.

central nervous system Part of the nervous system that includes the brain and spinal cord.

central vacuole Large organelle containing water, nutrients, and wastes; can take up to 90% of a plant cell’s volume.

cephalization Having a head region with a concentration of sensory organs and central nervous system.

cephalothorax The anterior part of the arachnid body, derived from the fusion of the head and thorax.

cerebellum Part of the brain that controls body position, coordination, and balance.

cerebrum Part of the brain that controls awareness and voluntary movements.

cervix Narrow part of the uterus where it connects with the vagina.

character displacement Occurs when two or more species within the same area develop different specializations in order to coexist.

chemical digestion Digestion in which large food molecules are broken down into small nutrient molecules.

chemical reaction A process that breaks or forms the bonds between atoms.

chemotroph Organism that obtains energy by oxidizing compounds in their environment.

childbirth Process through which a baby passes from the uterus, through the vagina, and out of the mother's body.

childhood Period between a baby's first birthday and puberty.

chitin A nitrogen-containing material found in the cell wall of fungi; also found in the shells of animals such as beetles and lobsters.

chlamydia Most common bacteria causing sexually transmitted disease (STD) in the United States.

chlorophyll Green pigment in leaves; helps to capture solar energy.

chloroplast The organelle in which photosynthesis takes place.

chromatin Complex of DNA and proteins; visible when a cell is not dividing.

chromosome DNA wound around proteins; forms during prophase of mitosis and meiosis.

chronic disease A disease that lasts for a long time, perhaps a few years or longer.

chronic obstructive pulmonary disease (COPD) A disease of the lungs in which the airways become narrowed; leads to a limitation of the flow of air to and from the lungs causing shortness of breath.

cilia Finger-like projects from the cells; can be found from the cells of mucous membranes.

circadian rhythms An organism's daily cycles of behavior.

classify To organize into groups or categories; scientists classify organisms by their physical features and how closely related they are.

climax community A stable community that is the end product of succession.

cloning Creating an identical copy of a gene, or an an individual with the same genes.

club mosses Seedless vascular plants that resemble mosses.

cnidarians Invertebrates that have radial symmetry; includes the jellyfish.

cocci Sphere-shaped bacteria or archaea.

cochlea Liquid-filled structure in the ear that senses vibrations and generates nerve impulses in response.

codominance A pattern of inheritance where both alleles are equally expressed.

commensalism type of symbiosis in which one species benefits while the other is not affected.

communication Any way that animals share information.

community Populations of different species that occupy the same area and interact with each other.

competition Organisms of the same or different species compete for a limited supply of at least one resource, thereby lowering the fitness of one organism by the presence of the other.

competitive exclusion principle Species less suited to compete for resources will either adapt, be excluded from the area, or die out.

complete digestive tract A digestive tract with two openings, a mouth and anus.

complete flowers Flowers that contain all four structures: sepals, petals, stamens, and one or more carpels.

compound Any combination of two or more elements.

concentration The amount of a substance in relation to the volume.

concussion Bruise on the surface of the brain; the mildest and most common type of brain injury.

conditioning Way of learning that involves a reward or punishment.

conifers Group of gymnosperms that bear cones; includes spruces, pine, and fir trees.

conjugation The transfer of genetic material between two bacteria.

connective tissue Tissue that is made up of different types of cells that are involved in structure and support of the body; includes blood, bone, tendons, ligaments, and cartilage.

consumer An organism that must eat other organisms to obtain energy and nutrients.

contraction Shortening of muscle fibers.

convergent adaptation The appearance of similar traits in groups of animals that are evolutionarily unrelated to each other.

cooperation Working together with others for the common good.

corals Cnidarians that live on ocean reefs in colonies.

cornea Clear, protective covering on the outside of the eye that helps focus light.

corolla The petals of a flower collectively are known as the corolla.

coronary heart disease The end result of the buildup of plaques within the walls of the coronary arteries.

courtship behaviors Special behaviors that help attract a mate.

cranium a braincase

crossing-over Exchange of DNA segments between homologous chromosomes; occurs during prophase I of meiosis.

cross-pollination Sexual reproduction in plants where sperm from the pollen of one flower is received by the ovary of another flower.

cuticle Waxy layer that aids water retention in plants.

cyanobacteria Photosynthetic bacteria.

cytokinesis Division of the cytoplasm after mitosis or meiosis.

cytokinins Plant hormone involved in cell division.

cytoplasm All the contents of the cell besides the nucleus, including the cytosol and the organelles.

cytoskeleton The internal scaffolding of the cell; maintains the cell shape and aids in moving the parts of the cell.

cytosol A fluid-like substance inside the cell; organelles are embedded in the cytosol.

D

daughter cell Cells that divide from the parent cell after mitosis or meiosis.

death rate Number of deaths within the population per unit time.

decomposer Organism that break down wastes and dead organisms and recycle their nutrients back into the environment.

dendrite Part of a neuron that receives nerve impulses from other cells and passes them on to the cell body.

dermis The layer of skin directly under the epidermis; made of a tough connective tissue that contains the protein collagen.

desertification A process leading to production of a desert of formerly productive land.

diabetes A disease in which the pancreas cannot make enough insulin.

diaphragm A sheet of muscle that extends across the bottom of the rib cage.

digestion Process of breaking down food into nutrients.

digestive system Body system that breaks down food, absorbs nutrients, and gets rid of solid food waste.

diffusion Movement of molecules from an area of high concentration to an area of low concentration; does not require energy.

diploid When a cell has two sets of chromosomes.

dispersion The spacing of individuals within a population.

display behavior Fixed set of actions that carries a specific message.

DNA Deoxyribonucleic acid; a nucleic acid that is the genetic material of all organisms.

DNA replication The synthesis of new DNA; occurs during the S phase of the cell cycle.

domain The least specific category of classification.

dominant Masks the expression of the recessive trait.

dormant Halting growth and development temporarily.

double helix The shape of DNA; a double spiral, similar to a spiral staircase.

drug Any chemical substance that affects the body or brain.

drug abuse Use of a drug without the advice of a doctor or for reasons other than those for which the drug was intended.

drug addiction Condition in which a drug takes over people's lives and they cannot stop using the drug even if they want to.

drug overdose Taking so much of a drug that it causes serious illness or death.

duodenum The first part of the small intestine; where most chemical digestion takes place.

E

ear Sense organ that detects sound.

ear canal Tube-shaped opening in the ear that carries sound waves to the eardrum.

eardrum Membrane in the ear that vibrates when sound waves hit it.

ecdysis The ability to regenerate lost limbs, as well as other body parts.

ecological succession The continual replacement of one community by another; occurs after some disturbance of the ecosystem.

ecology The scientific study of how living organisms interact with each other and with their environment.

ecosystem A natural unit composed of all the living forms in an area, functioning together with all the abiotic components of the environment.

ectothermic cold-blooded; temperature depends on the temperature of their environment.

eggs female gametes or sex cells

electron A negatively charged particle in the atom, found outside of the nucleus.

electron microscope Microscope used to create high magnification (magnified many times) and high resolution (very clear) images.

element A substance that cannot break down into a simpler substance with different properties.

elevation Measures how high land is above sea level.

embryo An animal or plant in its earliest stages of development, before it is born or hatched.

embryology The study of how organisms develop.

emigration Movement of individuals out of a population.

emphysema A chronic lung disease caused by loss of elasticity of the lung tissue.

endoplasmic reticulum (ER) A folded membrane organelle; rough ER modifies proteins and smooth ER makes lipids.

endostyle Used to gather food particles and move them along the digestive tract.

environmental tobacco smoke (ETS) Secondhand smoke, which greatly increases the risk of lung cancer and heart disease in nonsmokers.

enzyme A substance, usually a protein, that speeds up a biochemical reaction.

epidermis The outermost layer of the skin; forms the waterproof, protective wrap over the body's surface; made up of many layers of epithelial cells.

epididymis Male reproductive organ where sperm mature and are stored until they leave the body.

epiglottis A flap of connective tissue that closes over the trachea when food is swallowed; prevents choking or inhaling food.

epithelial tissue A tissue that is composed of layers of tightly packed cells that line the surfaces of the body; examples of epithelial tissue include the skin, the lining of the mouth and nose, and the lining of the digestive system.

erosion Process by which the surface of the Earth is worn away by the action of winds, water, waves, glaciers, etc.

esophagus The narrow tube that carries food from the throat to the stomach.

essential amino acids Amino acids that must come from the proteins in foods; you cannot make these amino acids.

estrogen The main sex hormone in females.

ethylene Plant hormone involved in fruit ripening and abscission.

Eukarya Domain in which cells have a nucleus; includes plants, animals, fungi, and protists.

eukaryote Cell belonging to the domain Eukarya (fungi, animals, protists, and plants); has membrane-enclosed nucleus and organelles.

evidence Something that gives us grounds for knowing of the existence or presence of something else.

evolution The process in which something passes to a different stage, such as a living organism turning into a more advanced or mature organism; the change of the inherited traits of a group of organisms over many generations.

evolutionary tree Diagram used to represent the relationships between different species and their common ancestors.

excretion The process of removing wastes from the body.

excretory system The organ system that maintains homeostasis by keeping the correct balance of water and salts in your body; also helps to release wastes from the body.

exhalation Pushing air out of the body through the nose or mouth.

exocuticle The thin and waxy water resistant outer layer of the cuticle.

experiment A test to see if a hypothesis is right or wrong; a test to obtain new data.

extensor The muscle that contracts to cause a joint to straighten.

external fertilization Reproduction where the eggs are fertilized outside the body.

external respiration The movement of oxygen into the body and carbon dioxide out of the body.

extinct Something that does not exist anymore; a group of organisms that has died out without leaving any living representatives.

extinction The cessation of existence of a species or group of taxa.

F

F1 generation The first filial generation; offspring of the P or parental generation.

F2 generation The second filial generation; offspring from the self-pollination of the F1 generation.

fallopian tubes Female reproductive organs through which eggs pass to reach the uterus, and where an egg may unite with a sperm.

feedback regulation Control of a biological process based on the effect of a stimulus.

fermentation Anaerobic respiration in which NAD^+ is recycled so that is can be reused in the glycolysis (the breakdown of glucose) process.

ferns Seedless vascular plants that have large, divided fronds.

fertilization Union of a sperm and egg; occurs in a fallopian tube.

fetus Stage of a developing baby between the end of the 8th week after fertilization and birth.

fever Higher than normal body temperature.

fibrin A tough protein that forms strands during the blood clotting process.

field scientist Scientists who work outdoors.

filter-feeder An organism that feeds by filtering organic matter out of water.

flagellum (plural flagella) A tail-like structure that projects from the cell body of certain prokaryotic and eukaryotic cells, and it usually functions in helping the cell move.

flexor The muscle that contracts to cause a joint to bend.

follicle Nest of cells in an ovary that enclose an egg; protects egg during maturation prior to ovulation.

food allergies A condition in which the immune system reacts to harmless substances in food as though they were harmful.

food chain A visual representation of the flow of energy from producers to consumers in a community.

food web A visual representation of the complex eating relationships in a community; a cross-linking of food chains.

fossil The preserved remains or traces of animals, plants, and other organisms from the distant past; examples include bones, teeth, impressions, and leaves.

fossil fuels Fuels made from partially decomposed organic matter that has been compressed underground for millions of years; examples are: coal, natural gas, and oil.

fossil record Fossils and the order in which fossils appear; provides important records of how species have evolved, divided and gone extinct.

fracture Bone injury, often called a *break*; usually caused by excess bending stress on bone.

fruiting body Specialized structure used in sexual reproduction; part of the fungus that produces the spores.

G

GAIA hypothesis The concept that the biosphere is itself a living organism.

Galápagos Islands A group of islands in the Pacific Ocean off South America; known for unusual animal life. Many scientists, including Charles Darwin, made many discoveries that led to and support the theory of evolution by natural selection, while studying the plants and animals on these islands.

gamete Haploid sex cell; egg or sperm.

ganglia A compact group of nerve cells having a specific function.

gas exchange The movement of oxygen across a membrane and into the blood and the movement of carbon dioxide out of the blood.

gastric mill A gizzard-like structure for grinding food.

gastrovascular cavity A large cavity having both digestive and circulatory functions.

gene The inherited unit of DNA that encodes for one protein (or one polypeptide).

gene therapy The insertion of genes into a person's cells to cure a genetic disorder.

genetics The study of inheritance.

genital herpes Common sexually transmitted disease (STD) that is caused by the herpes virus.

genome All of the genes in an organism.

genotype The genetic makeup of a cell or organism, defined by certain alleles for a particular trait.

genus The first word in the two word name given to every organism.

geographic isolation The separation of a population from the rest of its species due to some physical barrier, such as a mountain range, an ocean, or great distance.

geologic time scale A time scale used to describe when events happened in the history of Earth.

gibberellins Plant hormone involved in seed germination and stem elongation.

ginkgo Tree known as the *living fossil* because it is the only species left in the phylum Ginkgophyta.

gliding joint Joint structure that allows one bone to slide over the other; examples includes the joints in the wrists and ankles.

global warming Global increase in the Earth's temperature due to human activities that release greenhouse gasses into the atmosphere.

golgi apparatus The organelle where proteins are modified, labeled, packaged into vesicles, and shipped.

gonad Organ that produces gametes, such as the ovaries and testes.

gonorrhea Common sexually transmitted disease (STD); caused by bacteria.

gravitropism Plant growth towards or away from the pull of gravity.

greenhouse gases The cause of global warming by certain gases via the greenhouse effect.

groundwater Underground water reserves.

gymnosperms Seed plant where seeds are not enclosed by a fruit.

H

habitat Ecological or environmental area where a particular species live.

habituation Learning to get used to something that is not dangerous, after being exposed to it for awhile.

hallucinogenic drug Psychoactive drug that can cause strange sensations, perceptions, and thoughts.

halophiles Organisms that live and thrive in very salty environments.

hammer First of three tiny bones that pass vibrations through the ear.

haploid When a cell has only one set of chromosomes, typical of a gamete.

harem A group of females followed or accompanied by a fertile male; this male excludes other males access to the group.

hearing The ability to sense sound.

heart attack Event that occurs when the blood supply to a part of the heart is blocked.

hemoglobin Protein that moves oxygen throughout the blood.

hemophilia A group of hereditary diseases that affect the body's ability to control blood clotting.

hepatitis B Sexually transmitted disease (STD) that damages the liver and is caused by a virus called hepatitis B.

herbivore A consumer of producers in a community; often organisms that eat plants.

heterozygous Having two different alleles for a particular trait.

heterotroph Organism which obtains carbon from outside sources.

hibernation State in which an animal's body processes are slower than usual.

hinge joint Joint structure in which the ends of bones are shaped in a way that allows motion in two directions only (forward and backward); examples include the knees and elbows.

HIV The human immunodeficiency virus, which causes AIDS.

homeostasis Maintaining a stable internal environment despite changes in the environment.

homing The ability of an insect to return to a single hole among many other apparently identical holes, after a long trip or after a long time

homozygous Having identical alleles for a particular trait.

hormones Chemical messengers that signal responses to stimuli.

hornworts Seedless nonvascular plants with hornlike sporophytes.

horsetails Seedless vascular plants with hollow, rigid stems.

Human Genome Project International effort to sequence all the base pairs in human DNA; completed in 2003.

humidity The amount of water in the air.

hybrid The offspring of different species, genera, varieties or breeds.

hydropower Use of power from falling water or other water movement to generate and distribute electricity; also known as hydroelectric power.

hydroskeleton Fluid-filled body cavity that provides support for muscle contraction.

hyoid bone A U-shaped bone at the root of the tongue; in salamanders it is used to help catch prey.

hypertension Also called high blood pressure; a condition in which a person's blood pressure is always high; the systolic blood pressure is always 140 mm Hg or higher, and/or their diastolic blood pressure is always 90 mm Hg or higher.

hypertonic solution Having a higher solute concentration than the cell; cell will lose water by osmosis.

hyphae Thread-like structures which interconnect and bunch up into mycelium; helps bring food, such as a worm, inside the fungus.

hypothesis A proposed explanation for something that is testable.

hypotonic solution Having a lower solute concentration than the cell; cell will gain water by osmosis.

I

ileum The third part of the small intestine; covered with villi; the few remaining nutrients are absorbed in the ileum.

immigration Movement of individuals into a population from other areas.

immune response The specific third line of defense against pathogens; involves the immune system.

immune system System that protects the body from pathogens and other causes of disease.

immunity Ability to resist a pathogen because cells of the immune system remember the pathogen from a previous infection or vaccination.

incomplete digestive tract A digestive tract with only one opening.

incomplete dominance A pattern of inheritance where the offspring has a phenotype that is halfway between the two parents' phenotypes.

incomplete flowers Flowers that are missing one or more structures: sepals, petals, stamens, or carpels.

infancy The first year of life after birth.

infectious disease A disease that spreads from person to person.

inflammation Reaction causing redness, warmth, and pain that occurs at the site of an infection or injury.

ingredient A specific item that a food contains.

inhalation Taking air into the body through the nose and mouth.

inherited traits Features that are passed from one generation to the next.

innate behavior Any behavior that occurs naturally in all animals of a given species.

insight learning Learning from past experiences and reasoning.

instinct Any behavior that occurs naturally in all animals of a given species; another term for an innate behavior.

integumentary system The outer covering of the body; made up of the skin, hair, and nails.

internal fertilization Reproduction that occurs through the internal deposit of gametes.

internal respiration The exchange of gases between the blood and the cells of the body.

interphase Stage of the cell cycle when DNA is synthesized and the cell grows; composed of the first three phases of the cell cycle.

invasive species Exotic species, introduced into habitats, which then eliminate or expel the native species.

invertebrate Animal without a backbone.

involuntary muscle A muscle that a person cannot consciously control; cardiac muscle and smooth muscle are involuntary.

iris Colored structure at the front of the eye.

isotonic solution A solution in which the amount of dissolved material is equal both inside and outside the cell; no net gain or loss of water.

J

jejunum The second part of the small intestine; where most nutrients are absorbed into the blood; lined with tiny "fingers" called villi.

joint Point at which two or more bones meet.

K

keratin Tough, waterproof protein that is found in epidermal skin cells, nail, and hair.

keystone species A predator species that plays an important role in the community by controlling the prey population.

kidney Organ that filters and cleans the blood and forms urine; also maintains the volume of body fluids, maintains the balance of salt ions in body fluids, and excretes harmful metabolic by-products such as urea, ammonia, and uric acid.

kidney dialysis The process of artificially filtering the blood of wastes; a patient's blood is sent through a filter that removes waste products and the clean blood is returned to the body.

kidney failure When the kidneys are not able to regulate water and chemicals in the body or remove waste products from the blood.

L

lactic acid fermentation Anaerobic respiration that recycles NAD^+ for glycolysis (the breakdown of glucose); occurs in animals and some bacteria and fungi.

language Use of symbols or sounds to communicate.

large intestine The relatively wide tube between the small intestine and anus where excess water is absorbed from food waste.

larvae Young or non-adult insects.

larynx Found just below the point at which the pharynx splits into the trachea and the esophagus. Your voice comes from your larynx; air from the lungs passes across thin membranes in the larynx and produces sound; also called the voicebox.

latitude How far a biome is from the equator.

learned behavior Behavior that occurs only after experience or practice.

lens Clear, curved structure in the eye that focuses light on the retina.

leukemia Cancer of the blood or bone marrow; characterized by an abnormal production of blood cells, usually white blood cells.

life science The study of living organisms, and how they interact with each other and their environment.

lifestyle disease A disease that is caused by choices that people make in their daily lives.

ligament Fibrous tissue that connects bones to other bones; made of tough collagen fibers.

limiting factor A living or nonliving property of a population's environment, which regulates population growth.

lipid Class of organic compound that includes fats, oils, waxes and phospholipids; nutrients, such as fats, that are rich in energy.

liverworts Seedless nonvascular plants that can have flattened bodies resembling a liver.

lung cancer A disease where the cells that line the lungs grow out of control; the growing mass of cells pushes into nearby tissues and can affect how these tissues work.

lymph Yellowish fluid that leaks out of tiny vessels into spaces between cells in tissues.

lymphatic system A network of vessels and tissues that carry a clear fluid called lymph; includes lymph nodes, lymph ducts, and lymph vessels.

lymph nodes Small, oval structures located along lymphatic vessels that filter pathogens from lymph.

lymphocytes Type of white blood cells involved in an immune response.

lymphoma Cancer of white blood cells called lymphocytes.

lysosome Organelle which contains degradative enzymes; breaks down unneeded materials.

M

macroevolution Big evolutionary changes that result in new species.

macromolecule Very large molecules that make living organisms; includes carbohydrates, lipids, proteins, and nucleic acids.

main ingredient The ingredient that is present in the food in the greatest amount.

mammary glands Specialized sweat glands that produce milk.

mantle A fold of outer skin lining the shell of mollusks; releases calcium carbonate that is used to create the external shell.

marsupial A type of mammal where the female has an abdominal pouch or skin fold within which are mammary glands and a place for raising the young.

mass extinction An extinction when many species go extinct during a relatively short period of time.

mating Pairing of an adult male and female to produce young.

matter Anything that takes up space and has mass.

mechanical digestion Digestion in which large chunks of food are broken down into small pieces.

medusa Cnidarian with a bell-shaped body, with the mouth and tentacles facing downward, such as a jellyfish.

meiosis Nuclear division that results in haploid gametes.

melanin The brownish pigment that gives skin and hair their color.

menstrual cycle The monthly cycle of changes that occur in the uterus and ovaries.

menstruation Monthly shedding of the lining of the uterus through the vagina; also called a menstrual period.

metamorphosis The process by which insects transform from an immature or young insect into an adult insect.

metaphase Second phase of mitosis and meiosis (metaphase I and metaphase II) where the chromosomes are aligned in the center of the cell.

methanogens Organisms that live in swamps or in the guts of cows and termites and release methane gas.

microevolution Small changes in inherited traits; does not lead to the creation of a new species.

microscope A set of lenses used to look at things too small to be seen by the unaided eye.

microscopy All the methods for studying things using microscopes.

migration Movement of animals from one place to another; often seasonal.

minerals Chemical elements that are needed for body processes.

mitochondria Organelle where cellular respiration occurs; known as the ”powerhouse” of the cell because this is the organelle where the ATP that powers the cell is produced.

mitosis Sequence of steps in which a nucleus is divided into two daughter nuclei, each with an identical set of chromosomes.

molecule Any combination of two or more atoms.

molting The process by which arthropods shed their hard exoskeleton in order to grow.

monogamous A mating system where the couple pair for the duration of the breeding season, or sometimes for a few years or until one mate dies.

monotremes A group of mammals that lays eggs and feeds their young by "sweating" milk from patches on their bellies.

mosses Seedless nonvascular plants with tiny stem-like and stem-like structures.

motor division Division of the peripheral nervous system that carries messages from the central nervous system to internal organs, glands, and muscles.

motor neuron Neuron that carries nerve impulses from the central nervous system to internal organs, glands, or muscles.

movable joint Most mobile type of joint; the most common type of joint in the body.

mucus Sticky, moist substance that coats mucous membranes.

muscle fibers Long, thin cells that can contract; also called muscle cells.

muscular system The body system that allows movement.

muscular tissue Tissue that is composed of cells that have filaments that move past each other and change the size of the cell. There are three types of muscle tissue: smooth muscle, skeletal muscle, and cardiac muscle.

mutagen A chemical or physical agent that can cause changes to accumulate in DNA.

mutation A change in the nucleotide sequence of DNA.

mutualism A type of symbiosis in which both species benefit.

mycelial fragmentation Asexual reproduction involving splitting off of the mycelia; a fragmented piece of mycelia can eventually produce a new colony of fungi.

mycelium Help the fungi absorb nutrients from living hosts; composed of hyphae.

mycorrhizal symbiosis A relationship between fungi and the roots of plants where both benefit; the plant provides sugar to the fungus; the fungi provides minerals and water to the roots of the plant.

myopia Vision problem in which nearby objects are clear but distant objects look blurry; also called nearsightedness.

MyPlate Visual representation of the relative daily portions of various food groups; replaced MyPyramid in 2011.

MyPyramid Diagram that shows how much you should eat each day of foods from six different food groups.

N

nacre The iridescent inner shell layer produced by some bivalves, some gastropods, and some cephalopods; also known as mother of pearl.

natural resources Naturally occurring substances necessary for the support of life.

natural selection Causes beneficial heritable traits to become more common in a population, and unfavorable heritable traits become less common.

negative feedback loop When the response to a stimulus decreases the effect of the original stimulus.

nematocysts Specialized cells in cnidarians that can release a small thread-like structure and toxins to capture prey.

neocortex Site of the cerebral cortex where most of higher brain functions occur.

nephron Tiny, tube-shaped filtering unit found inside each kidney.

nerve Bundle of individual nerve cells.

nerve impulse Electrical signal that is transmitted by neurons.

nerve net Interconnected neurons that send signals in all directions.

nervous system Body system that controls all the other systems of the body.

nervous tissue Tissue composed of nerve cells (neurons) and related cells.

neuron Nerve cell that carries electrical messages.

neurotransmitter Chemical that carries nerve impulses from the axon of one neuron to the dendrite of the next neuron.

neutron The non-charged particle of the atom; located in nucleus of the atom.

niche A specific role that an organism occupies within an ecosystem.

nictitating membrane A third transparent eyelid.

nitrogen fixation Process by which gaseous nitrogen is converted into chemical forms that can be used by plants.

noninfectious disease Disease that does not spread from person to person.

nonrenewable resource A natural resource that exists in fixed amounts and can be consumed or used up faster than it can be made by nature.

nonvascular plants Plants that do not have vascular tissue to conduct food and water.

notochord A hollow nerve cord along the back.

nuclear envelope A double membrane that surrounds the nucleus; helps regulate the passage of molecules in and out of the nucleus.

nuclear power A nonrenewable resource, where nuclear fission is used to generate energy.

nucleic acid Class of organic compound that includes DNA and RNA.

nucleoid The prokaryotic DNA consisting of a condensed single chromosome.

nucleotide The units that make up DNA; consists of a 5-carbon sugar, a phosphate group, and a nitrogen-containing base.

nucleus Membrane enclosed organelle in eukaryotic cells that contains the DNA; primary distinguishing feature between a eukaryotic and prokaryotic cell; the information center, containing instructions for making all the proteins in a cell, as well as how much of each one.

nutrients Chemicals in food that your body needs.

nutrition facts label The label on packaged food that shows the nutrients in the food.

nymphs A developmental stage of insects, where the young is usually similar to the adult.

O

obesity Having a very high percentage of body fat; obese people are at least 20 percent heavier than their healthy weight range.

observational learning Learning by watching and copying the behavior of someone else.

ocean acidification Process whereby the oceans' uptake of anthropogenic carbon dioxide from the atmosphere causes an ongoing decrease in ocean pH.

oil gland Skin organ that secretes an oily substance, called sebum, into the hair follicle.

omnivore A consumer in a community that eat both producers and consumers; usually eaters of both plants and animals.

omnivorous Eating both plant and animal material.

optical (light) microscope A microscope that focuses light, usually through a glass lens; used by biologists to visualize small details of biological specimens.

organ A group of tissues that work together to perform a common function.

organelle Small structure found in cells; has specialized functions; many are membrane-bound, such as mitochondria, plastids, and vacuoles. Membrane-bound organelles are found only in eukaryotic cells.

organic compound Compounds made up of a carbon backbone and associated with living things.

organism A living thing.

organ system A group of organs that work together to perform a common function.

osmosis Diffusion of water across a membrane.

outdoor air pollution Chemical, physical, or biological agents that modify the natural characteristics of the atmosphere, and cause unwanted changes to the environment and to human health.

oval window Membrane in the ear that passes vibrations from the stirrup to the cochlea.

ovaries Female reproductive organs that produce eggs and secrete estrogen.

ovary Enlarged part of the carpel where the ovules are contained.

ovulation Release of an egg by an ovary.

P

paleontologists Scientists who study fossils to learn about life in the past.

paralysis Inability to feel or move parts of the body.

parasite The organism that benefits in a relationship between two organisms in which one is harmed.

parasitism A type of symbiosis in which the parasite species benefits, while the host species is harmed.

parasympathetic division Division of the autonomic nervous system that controls body processes under nonemergency conditions.

parent cell Cell that divides into daughter cells after mitosis or meiosis.

parthenogenesis Reproduction where an unfertilized egg develops into a new individual.

passive transport Movement of molecules from an area of higher concentration to an area of lower concentration; does not require energy.

pathogen A disease causing agent.

pearl The hard, round object produced within the mantle of a living shelled mollusk.

pedigree A chart which shows the inheritance of a trait over several generations.

pedipalps The second pair of arachnid appendages used for feeding, locomotion, and/or reproductive functions.

pentadactyl Having five fingers or toes.

peptidoglycan Complex molecule consisting of sugars and amino acids that makes up the bacterial cell wall.

Periodic Table Table that organizes elements according to their unique characteristics, like atomic number, density, boiling point, and other values.

peripheral nervous system All the nerves of the body that lie outside the central nervous system.

phagocytes A type of white blood cells that travel to sites of inflammation and destroy pathogens and debris.

phagocytosis The process by which phagocytes engulf and destroy pathogens or debris.

pharynx A long tube that is shared with the digestive system; both food and air pass through the pharynx.

phenotype The physical appearance that is a result of the genotype.

pheromones Chemicals secreted by animals, especially insects, that influence the behavior or development of others within the same species.

phloem Vascular tissue that carries the sugars made during photosynthesis (in the leaves) to other parts of the plant.

phospholipid A lipid molecule with a hydrophilic head and two hydrophobic tails; makes up the cell membrane.

photosynthesis The process by which specific organisms (including all plants) use the sun's energy to make their own *food* from carbon dioxide and water; process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy.

phototropism Plant growth towards or away from light.

physical dependence Condition in which drug abusers need a drug to feel well physically.

physical fitness The ability of your body to carry out your daily activities without getting out of breath, sore, or overly tired.

pineal eye An eye-like structure that develops in some cold-blooded vertebrates.

pinna Outer part of the ear that gathers sound waves.

pioneer species The species that first inhabit a disturbed area.

pivot joint Joint structure in which the end on one bone rotates within a ring-type structure which can be made partly of bone and partly of ligament.

placenta Spongy mass of blood vessels from the mother and fetus that allows substances to pass back and forth between the mother's blood and the fetus's blood.

placental A type of mammal that has a placenta that nourishes the fetus and removes waste products.

placoid Plate-like, as in the scales of sharks.

plaque Cell pieces made up of fatty substances, calcium, and connective tissue that build up around the area of inflammation; builds up on the lining of blood vessels.

plasma The straw-colored fluid in blood; about 90 percent water and about 10 percent dissolved proteins, glucose, ions, hormones, and gases.

plasma membrane Surrounds the cell; made of a double layer of specialized lipids, known as phospholipids, with embedded proteins; regulates the movement of substances into and out of the cell; also called the cell membrane.

plasmid Small circular piece of DNA; found in prokaryotic cells.

platelets Fragments of larger cells that are important in blood clotting.

pneumonia An illness in which the alveoli become inflamed and flooded with fluid.

poikilothermic Cold-blooded; without the ability to independently warm the blood.

polygamous A mating system in which where there is more than one mate.

polygenic inheritance A pattern of inheritance where the trait is controlled by many genes and each dominant allele has an additive effect.

polyp Cnidarian with a cup-shaped body directed upward.

population A group of organisms belonging to the same species, that live in the same area, and interact with one another.

population growth rate How the population size changes per unit of time.

positive feedback loop When the response to a stimulus increases the original stimulus.

precipitation Water that falls to the earth in the form of rain, snow, sleet, hail.

precocial Newborn that are independent at birth or hatching and require little parental care.

predation An interaction where a predator organism feeds on another living organism or organisms, known as prey.

primary pollutants Substances released directly into the atmosphere by processes such as fire or combustion of fossil fuels.

primary succession Ecological succession that occurs in disturbed areas that have no or little soil, i.e. after a glacier retreats.

producer An organism that can absorb the energy of the sun and convert it into food through the process of photosynthesis; i.e. plants and algae.

product The end result of a reaction.

prokaryote A microscopic single-celled organism, including bacteria and cyanobacteria; does not have a nucleus with a membrane or other specialized organelles.

prophase Initial phase of mitosis and meiosis (prophase I and prophase II) where chromosomes condense, the nuclear envelope dissolves and the spindle begins to form.

protein Organic compound made up of smaller molecules called amino acids; performs many functions in the cell.

protist Eukaryotic organism that belongs to the kingdom Protista; not a plant, animal or fung

proton The positively charged particle of the atom; located in nucleus of the atom.

protozoa Animal-like protists.

pseudopodia A moving fake foot; the cell surface extends out a membrane and the force of this membrane propels the cell forward.

puberty Stage of life when a child becomes sexually mature.

pulmonary circulation The part of the cardiovascular system which carries oxygen-poor blood away from the heart to the lungs, and returns oxygen-rich blood back to the heart.

Punnett square Visual representation of a genetic cross that helps predict the expected ratios in the offspring, first described by Reginald C. Punnett in the early 20th century.

pupa Insect metamorphosis stage in which wing development begins.

pupil Black opening in the iris that lets light enter the eye.

Q

quadrupedal four-footed

R

radial symmetry A body plan in which any cut through the center results in two identical halves.

radiometric dating A method to determine the age of rocks and fossils in each layer of rock; measures the decay rate of radioactive materials in each rock layer.

radula A molluscan feeding structure, composed mostly of chitin.

reactant The raw ingredients in a chemical reaction.

recessive Expression is masked by the dominant factor (allele); only expressed if both factors are recessive.

recombinant DNA DNA formed by the combination of DNA from two different sources, such as placing a human gene into a bacterial plasmid.

recycling The breaking down of an item into raw materials to make new items.

red blood cells Flattened disk-shaped cells that carry oxygen, the most common blood cell in the blood. Mature red blood cells do not have a nucleus.

reducing Minimizing the use of resources.

reflex arc Path of nerve impulses that bypass the brain for a quicker response.

reflex behaviors The only truly innate behaviors in humans, occurring mainly in babies.

renewable resources Resources that are replenished by natural processes at about the same rate at which they are used.

reproductive isolation Allopatric and sympatric speciation; isolation due to geography or behavior, resulting in the inability to reproduce.

respiration The process of getting oxygen into the body and releasing carbon dioxide.

respiratory disease A disease of the lungs, bronchial tubes, trachea, nose, and/or throat.

respiratory system The organ system that allows oxygen to enter the body and carbon dioxide to leave your body.

retina Layer of light-sensing cells that covers the back of the eye.

ribosome The cell structure on which proteins are made; not surrounded by a membrane; found in both prokaryotic and eukaryotic cells.

RNA The nucleic acid that carries the information stored in DNA to the ribosome.

rough endoplasmic reticulum The part of the ER with ribosomes attached; proteins can be modified in the rough ER before they are packed into vesicles for transport to the golgi apparatus.

runoff Water that is not absorbed by the soil that eventually returns to streams and rivers.

S

scanning acoustic microscope A microscope that focuses sound waves instead of light.

scanning electron microscope (SEM) A microscope that scans the surfaces of objects with a beam of electrons to produce detailed images of the surfaces of tiny things.

scientific method A careful way of asking and answering questions to learn about the physical world that is based on reason and observable evidence.

scientific theory A well-established set of explanations that explain a large amount of scientific information.

secondary pollutants Substances formed when primary pollutants interact with sunlight, air, or each other.

secondary succession Ecological succession that occurs in disturbed areas that have soil to begin with, i.e. after a forest fire.

seedless vascular plants Plants with vascular tissue but no seeds.

segmentation A body plan that has repeated units or segments.

selectively permeable Semipermeable; property of allowing only certain molecules to pass through the cell membrane.

semen ”Milky” liquid that contains sperm and secretions of glands; passes through the urethra and out of body.

semicircular canals Liquid-filled part of the ear that senses changes in position and generates nerve impulses in response.

semiconservative replication Describes how the replication of DNA results in two molecules of DNA, each with one original strand and one new strand.

semilunar (SL) valves Found in the arteries leaving the heart; prevents blood flowing back from the arteries into the ventricles.

semipermeable Allowing only certain materials to pass through; characteristic of the cell membrane.

sensory division Division of the peripheral nervous system that carries messages from the sense organs and internal organs to the central nervous system.

sensory neuron Neuron that carries nerve impulses from sense organs or internal organs to the central nervous system.

sepals Outermost layer of the flower that is usually leaf-like and green.

serving size Tells you how much of the food you should eat to get the nutrients listed on the label.

sessile Permanently attached and not freely moving.

sex-linked inheritance The inheritance of traits that are located on genes on the sex chromosomes.

sex-linked trait A trait that is due to a gene located on a sex chromosome, usually the X-chromosome.

sexual dimorphism Extreme difference between the sexes.

sexually transmitted disease (STD) Disease that spreads through sexual contact and is caused by a pathogen.

sexual reproduction Reproduction where gametes from two parents combine to make an individual with an unique set of genes.

sickle cell disease A blood disease that is caused by abnormally-shaped blood protein hemoglobin.

silk A thin, strong, protein strand extruded from the spinnerets; most commonly found on the end of the abdomen of spiders.

sister chromatids The two identical molecules of DNA in a chromosome after the DNA is replicated.

skeletal muscle The muscle that is usually attached to the skeleton.

skeletal system Body system that is made up of bones, cartilage, and ligaments.

skeleton Sturdy scaffolding of bones and cartilage that is found inside vertebrates.

slash-and-burn agriculture A method of agriculture in the tropics in which the forest vegetation is cut down and burned, then crops are grown for a few years, and then the forest is allowed to grow back.

small intestine The narrow tube between the stomach and large intestine where most chemical digestion and absorption of nutrients take place.

smooth endoplasmic reticulum Part of the ER that does not have ribosomes attached; where lipids are synthesized.

smooth muscle Involuntary muscle found within the walls of organs and structures such as the esophagus, stomach, intestines, and blood vessels.

social animals Animals that live in groups with other members of their species.

solar power The use of solar cells to convert sunlight into electricity.

somatic cell A body cell; not a gamete.

somatic nervous system Part of the motor division that carries nerve impulses to muscles that control voluntary body movements.

speciation The creation of a new species; either by natural or artificial selection.

species A group of individuals that are genetically related and can breed to produce fertile young; the second word in the two word name given to every organism is the species name.

sperm male gametes or sex cells

spinal cord Long, tube-shaped bundle of neurons that carry nerve impulses back and forth between the body and brain.

spindle Fibers that move chromosomes during mitosis and meiosis.

spiracles Openings on the sides of the insect abdomen, through which air is taken in.

spirilli Spiral-shaped bacteria or archaea.

sponging The ability of an insect mouthpart to absorb liquid food.

sporangium Capsule, formed by the sporophyte, which releases spores.

spore The basic reproductive unit of fungi.

sprain A ligament injury; usually caused by the sudden overstretching of a joint which causes tearing.

stamen The part of the flower consisting of a filament and an anther that produces pollen.

starch Large, complex carbohydrate; found in foods such as vegetables and grains; broken down by the body into sugars that provide energy.

stigma The knoblike section of the carpel where the pollen must land for fertilization to occur.

stimulant drug Psychoactive drug that speeds up the nervous system.

stirrup Last of three tiny bones that pass vibrations through the ear.

stomach The sac-like organ at the end of the esophagus where proteins are digested.

stomata Special pores in leaves; carbon dioxide enters the leaf and oxygen exits the leaf through these pores.

strain An injury to a muscle in which the muscle fibers tear because the muscle contracts too much or contracts before the muscle is warmed up.

stroke A loss of brain function due to a blockage of the blood supply to the brain.

stroma Fluid in the chloroplast interior space; surrounds the thylakoids.

stromolites Fossils made of algae and a kind of bacteria; some of the oldest fossils on Earth.

sunburn A burn to the skin that is caused by overexposure to UV radiation from the sun's rays or tanning beds.

sweat gland Gland that opens to the skin surface through skin pores; found all over the body; secretes sweat.

symbiosis Close and often long-term interactions between different species, in which at least one species benefits.

sympathetic division Division of the autonomic nervous system that prepares the body for fight or flight in emergencies.

sympatric speciation Speciation that occurs when groups from the same species stop interbreeding, because of something other than physical separation, such as behavior.

synapse Place where the axon of one neuron meets the dendrite of another neuron.

syphilis Very serious STD that is caused by bacteria.

systemic circulation The portion of the cardiovascular system which carries oxygen-rich blood away from the heart to the body, and returns oxygen-poor blood back to the heart.

T

tapeworms Intestinal parasites in the phylum Platyhelminthes.

taste buds Tiny bumps on the tongue that contain taste neurons.

taxonomy The science of naming and classifying organisms.

telophase Final phase of mitosis and meiosis (telophase I and telophase II) where a nuclear envelop forms around each of the two sets of chromosomes.

tendon A tough band of connective tissue that connects a muscle to a bone.

teratogen A chemical that causes deformities.

terrestrial biomes Biomes defined based on plant and climatic factors.

testes Male reproductive organs that produce sperm and secrete testosterone.

testosterone The main sex hormone in males.

theory of evolution Theory developed by Charles Darwin that explains how populations of organisms can change over time.

thermophiles Organisms that live in very hot environments, such as near volcanoes and in geysers.

thigmotropism Differential plant growth in response to contact with an object.

thylakoid Flattened sacs within the chloroplast; formed by the inner membranes.

tissue A group of specialized cells that function together.

tolerance Condition in which people need to take more of a drug to feel the same effects as when they first started using the drug.

touch The sense of pain, pressure, or temperature.

trachea A long tube that leads down to the chest where it divides into the right and left bronchi in the lungs; also called the windpipe.

trait A feature or characteristic of an organism; for example, your height, hair color, and eye shape are physical traits.

transcription The synthesis of a RNA that carries the information encoded in the DNA.

transduction Transfer of DNA between two bacteria; occurs with the aid of a virus (bacteriophage).

trans fat Manufactured fat that is added to certain foods to keep them fresher for longer.

transformation The process by which bacteria pick up foreign DNA and incorporate it in their genome.

translation The synthesis of proteins as the ribosome reads each codon in RNA, which code for a specific amino acid.

transmission electron microscope (TEM) A microscope that focuses a beam of electrons through an object and can make an image up to two million times bigger, with a very clear image (”high resolution”).

transpiration Process by which water leaves a plant by evaporating from the leaves.

trophic level A level of the food chain reflected in the ecological pyramid.

tropism Plant growth response towards or away from a stimulus.

tuberculosis (TB) A common and often deadly infectious disease caused by a type of bacterium called mycobacterium.

tumor Mass of cells that grow out of control; associated with cancer.

tympanum Equivalent to the middle ear; used in hearing.

type 1 diabetes The type of diabetes that occurs when the immune system attacks normal cells of the pancreas.

type 2 diabetes Type of diabetes that occurs when body cells no longer respond to insulin.

U

umbilical cord Tube containing blood vessels that connects a fetus to the placenta.

universal donor A person with type O positive blood; type O red blood cells do not have any antigens on their membranes and so would not cause an immune reaction in the body of a recipient.

universal recipient A person with type AB positive blood; the blood plasma of AB blood does not contain any anti-A or anti-B antibodies. People with type AB blood can receive any ABO blood type.

urinary bladder Organ that collects the urine which comes from the kidneys.

urinary system The organ system that makes, stores, and gets rid of urine.

urinary tract infection (UTI) Bacterial infections of any part of the urinary tract.

urination The process of releasing urine from the body.

urine A liquid that is formed by the kidneys when they filter wastes from the blood; contains mostly water and also dissolved salts and nitrogen-containing molecules.

uterus Female reproductive organ where a baby develops until birth.

V

vaccination Deliberate exposure to a pathogen in order to bring about immunity without causing disease.

valarian respiration Respiration in which the capillary beds are spread throughout the epidermis, so that gases can be exchanged through the skin.

valves In the heart; keep the blood flowing in one direction.

vascular tissue Tissues that conduct food, water, and nutrients in plants.

vector An organism that carries pathogens from one person or animal to another.

veins Blood vessels that carry blood back to the heart.

ventricle One of the two muscular V-shaped chambers that pump blood out of the heart.

vesicle Small membrane-enclosed sac; transports proteins around a cell or out of a cell.

vestigial structure Body part that, through evolution, has lost its use, such as a whale's pelvic bones.

villi Contain microscopic blood vessels; nutrients are absorbed into the blood through these tiny vessels; located on the jejunum and the ileum.

visible light Electromagnetic radiation that humans can detect with their eyes.

vision The ability to see light.

vitamins Substances that the body needs in small amounts to function properly.

vivipary A reproductive system in most mammals and some reptiles and fish, in which living young are produced rather than eggs laid.

voluntary muscle A muscle that a person can consciously control; skeletal muscle is voluntary.

W

waterborne diseases Diseases caused by organisms transmitted via contaminated water.

water pollution The contamination of water bodies by substances, mostly anthropogenic, which cause a harmful effect on living organisms.

water vascular system A network of fluid-filled canals; functions in gas exchange, feeding, and also in locomotion.

wavelength The distance from any point on one wave to the same point on the next wave.

whisk ferns Seedless nonvascular plants with tiny stem-like and stem-like structures.

white blood cells Nucleated blood cells that are usually larger than red blood cells; defend the body against infection by bacteria, viruses, and other pathogens.

wind power The conversion of wind energy into electricity via wind turbines.

withdrawal Symptoms like vomiting, diarrhea, or depression that can occur when people stop using a drug.

X

xylem Vascular tissue responsible for the transport of water and nutrients from the roots to the rest of the plant.

Y

Z

zygote Cell that forms when a sperm and egg unite; the first cell of a new organism.